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WATER RESOURCES OF THE GRAND RAPIDS AREA, MICHIGAN

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WATER RESOURCES OF THE GRAND RAPIDS AREA, MICHIGAN

By G. J. Stramel, C. O. Wisler, and L. B. Laird

Washington, D. C., 1954

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PREFACE

This report is one of a series concerning the water resources of selected industrial areas of national importance and has been prepared at the request of the Business and Defense Services Administration of the Department of Commerce. It is intended to provide information of value for national defense and related purposes as well as basic data on the water resources of the Grand Rapids area. The series is being prepared in the Water Resources Division with the assistance of J. B. Graham and K. A. MacKichan of the Water Utilization Section, Technical Coordination Branch. This report was prepared by G. J. Stramel, under the supervision of J. G. Ferris, district engineer (Ground Water Branch); by C. O. Wisler, under the supervision of A. D. Ash, district engineer (Surface Water Branch); and by L. B. Laird, under the supervision of W. L. Lamar, district chemist (Quality of Water Branch).

Most of the water-resources data in this report have been collected by the U. S. Geological Survey in cooperation with agencies of the State of Michigan and local governments. Additional data were obtained from industries in the Grand Rapids area.

Those who have contributed data for the report are: J. G. Rulison, chief, Water Resources Section, Geological Survey Division, Michigan Department of Conservation; L. F. Oeming and Norman Billings of the Michigan Water Resources Commission; Paul Goebel, mayor, G. E. Bean, city manager, C. W. Darling, service director, Lester Harris, city chemist, Millard Moore, city engineer, John Knoll, engineer, and Henry Spenski, registrar, of the city of Grand Rapids; Hewey Gork, city manager, and Clifford Paige, city engineer, of East Grand Rapids; Kenneth Jones, supervisor, and Paul Spellman, engineer, of Wyoming Township; Calvin DeBoer, water superintendent, city of Grandville; John Kasselman, industrial commissioner, Grand Rapids Chamber of Commerce. Well-drilling contractors, C. S. Raymer of Grand Rapids, and the Layne-Northern Company, Inc., of Lansing, provided many well records and other pertinent information related to ground water.

Appreciation is expressed to the firms of Hamilton, Weeber, and Ward, and Williams and Works for the reports and data which they generously provided.

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WATER RESOURCES OF THE GRAND RAPIDS AREA, MICHIGAN

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ABSTRACT

The Grand Rapids area, Michigan, has three sources from which to obtain its water supply: Lake Michigan, the Grand River and its tributaries, and ground water. Each of the first two and possibly the third is capable of supplying the entire needs of the area.

This area is now obtaining a part of its supply from each of these sources. Of the average use of 50 mgd (million gallons per day) during 1951, Lake Michigan supplied 29 mgd; the Grand River and its tributaries supplied 1 mgd; and ground water supplied 20 mgd.

Lake Michigan offers a practically unlimited source of potable water. However, the cost of delivery to the Grand Rapids area presents an economic problem in the further development of this source. Even without storage the Grand River can provide an adequate supply for the city of Grand Rapids. The present average use of the city of Grand Rapids is about 30 mgd and the maximum use is about 60 mgd, while the average flow of the Grand River is 2,495 mgd or 3,860 cfs (cubic feet per second) and the minimum daily flow recorded is 246 mgd. The quality and temperature of water in the Grand River is less desirable than Lake Michigan water. However, with proper treatment its chemical quality can be made entirely satisfactory.

The city of Grand Rapids is actively engaged in a study that will lead to the expansion of its present water-supply facilities to meet the expected growth in population in Grand Rapids and its environs.

Ground-water aquifers in the area are a large potential source of supply. The Grand Rapids area is underlain by glacial material containing a moderately hard to very hard water of varying chemical composition but suitable for most uses. The glacial outwash and lacustrine deposits bordering principal streams afford the greatest potential for the development of large supplies of potable ground water. Below the glacial drift, bedrock formations contain water that is extremely hard and moderately to highly mineralized. Thus the major sources of usable ground water are the glacial drift and some parts of the bedrock. Wherever the bedrock yields large quantities of water, the water is generally of inferior quality. Any development should be preceded by test drilling and careful hydrologic and geologic studies of the area under consideration and chemical analysis of the water found.

INTRODUCTION

Purpose of This Report

This report summarizes the available streamflow data in the Grand Rapids area and evaluates the ground-water resources insofar as information is available. It furnishes data on the chemical quality of raw and finished water supplies; gives some information on floods on the Grand River; and outlines the outcrops of the various bedrocks and glacial deposits and briefly defines their water-bearing characteristics. This compilation and review of the available data is not intended to provide the final answer for any specific water-supply problem.

Description of the Area

The area termed "the Grand Rapids area" in this report includes the townships of Ada, Alpine, Byron, Caledonia, Cannon, Cascade, Gaines, Grand Rapids, Paris, Plainfield, Walker, and Wyoming. It contains the cities of Grand Rapids, East Grand Rapids, Grandville, Caledonia, and several smaller population centers. The area covers about 432 square miles and lies almost entirely in the Grand River basin about 30 miles east of Lake Michigan. A small part of the area is drained by the Black and Rabbit Rivers. The altitude of the area ranges from about 600 to 1,000 feet. The Grand River flows through the area and has cut deeply into the glacial drift, reaching bedrock in the central part of the city. Grand Rapids takes its name from the rapids at the bedrock outcrop. The Grand River valley is marked by terraces and flat plains. The principal tributaries to the Grand River in this area are Thornapple River, Rogue River, Mill Creek, Indian Creek, Plaster Creek, Buck Creek, and Rush Creek. The surface soils are composed of sands, sandy clays, clays, and gravels.

The population of the Grand Rapids area in 1950 was 266,306, of which 66 percent was within the city of Grand Rapids. Of the remaining population, 72 percent is within the four central townships of Grand Rapids, Paris, Walker, and Wyoming. Four incorporated cities lie wholly within the Grand Rapids area. In 1950, the populations of these cities were: Grand Rapids, 176,515; East Grand Rapids, 6,403; Grandville, 2,022; Caledonia, 619. Rockford, with a population of 1,937, lies partly within the area. The growth in population of the Grand Rapids area is shown in figure 1.

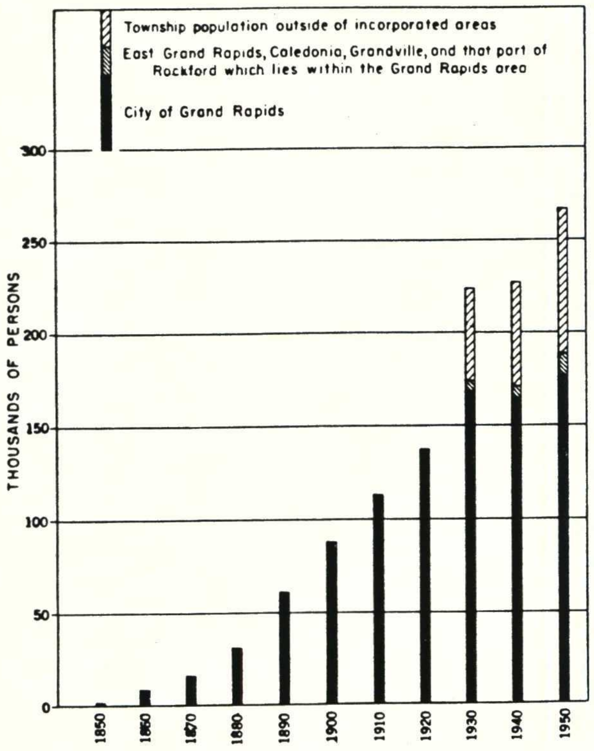


Figure 1.—Population growth in the Grand Rapids area, 1850—1950.

The greatest growth in industrial development in this area has occurred in the past 30 years. Except for the Detroit and perhaps the Flint areas, it is the most important industrial center in Michigan.

In October 1952, 700 industrial establishments in the Grand Rapids area employed 52,000 persons, of whom about 44,500 were employed by 393 establishments. Sixteen plants each employed 500 or more; 64 employed 100-150 each; and 620 employed 100 or fewer. Seventy-six of all industrial firms were furniture and woodworking plants, 123 were engaged in the metal trades, and the rest were diversified.

Grand Rapids, the second largest city in Michigan, is served by four railroads and by many good highways, as shown on plate 1. It is also served by several airlines having connections with principal cities in the United States.

Climate

Grand Rapids is in the Great Lakes region near the eastern shore of Lake Michigan, and its climate is influenced by the presence of water, which moderates the extreme cold of the winter and the heat of the summer.

The average monthly air temperature is shown in figure 2. The average temperature at Grand Rapids for the 66-year period upon which this figure is based is 48.2 F. The variation of the mean annual temperature from this value has never exceeded 4 F. The highest temperature on record (instantaneous maximum) is 108 F, and the lowest (instantaneous minimum) is -24 F. On an average, the temperature exceeds 90 F on 14 days a year; on 129 days it drops below 32 F; and on 4 days it falls below 0 F.

The annual precipitation at Grand Rapids during the last 83 years has ranged from a minimum of 20.92 inches in 1930 to a maximum of 52.14 inches in 1883, and averaged 33.89 inches. The variations in monthly and annual precipitation are shown in figure 3. The months of highest precipitation are May, June, and September, and more than half of the annual precipitation occurs between May 1 and the middle of October—the growing season.

The average annual snowfall for the period 1893—1952 is 56.4 inches. Snow may be expected to fall at any time between the middle of November and the middle of March, although it has fallen as early as September and as late as June. (See fig. 3.)

SOURCES OF WATER

The sources of water supply for the Grand Rapids area are Lake Michigan, the Grand River and its tributaries, and ground water. Each of the first two and possibly the third source is capable of supplying the entire needs of the Grand Rapids area for a great many years to come. The characteristics and potentialities of each will now be considered.

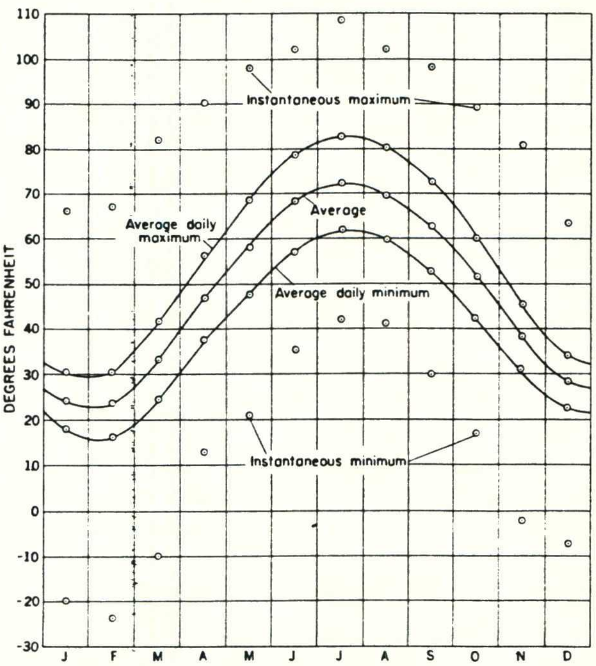


Figure 2.—Monthly air temperatures at Grand Rapids, 1886—1952.

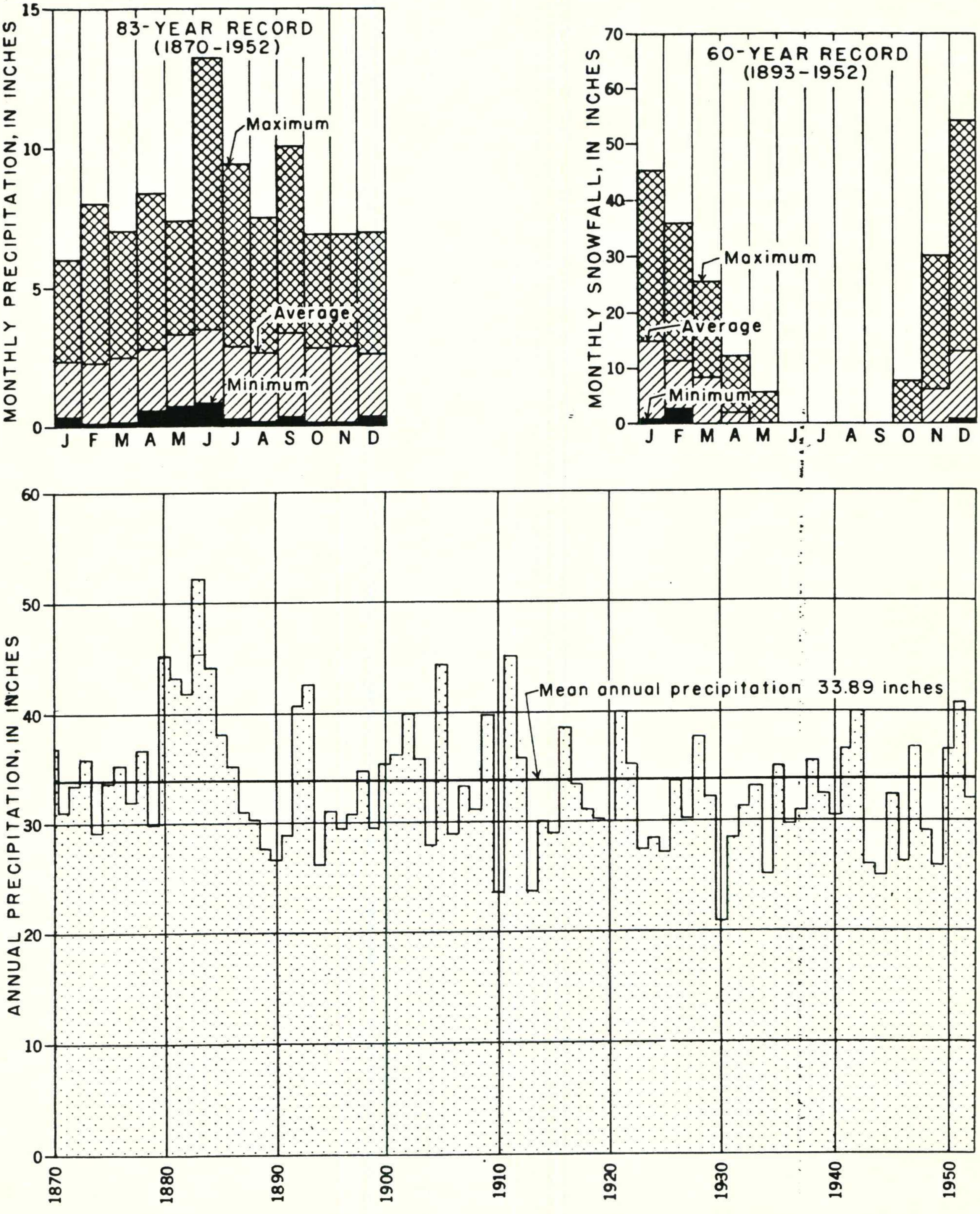


Figure 3. —Precipitation records at Grand Rapids.

Table 1. —Chemical quality of water from Lake Michigan and selected streams in the Grand Rapids area

[Chemical results in parts per million]

Location	No. on pl. 1	Date	Instantaneous discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color
Lake Michigan, Grand Rapids intake[1]	....	4-22-52	....	9.0	....	34	10	8.7		135	26	6	0.11	......	205	132	21	....	....	......
Lake Michigan, Grand Rapids intake[1]	....	5-14-51	....	5.4	....	37	11	6		146	23	6	......	......	206	138	18	....	....	......
Lake Michigan, Grand Rapids intake[1]	....	6-12-50	....	4 0	....	35	11	5.1		139	21	5	......	......	169	132	18	....	8.3	......
Grand River at water treatment plant[1]	....	1930-39	....	......	....	......	....	....	....	[2]165	......	......	......	......	....	[2]264	[2]63	....	....	[2]27
Grand River at municipal sewage pumping station	21	12- 1-52	2,740	7.6	0.02	76	20	16	2.9	254	57	21	.2	2.9	346	274	64	564	7.5	7
Thornapple River near Caledonia	19	12- 1-52	600	11	.01	75	22	4.4	1.5	289	42	4.5	.1	1.7	308	278	41	510	7.8	6
Rogue River near Rockford	20	12- 2-52	220	9.5	.03	72	22	14	1.9	219	84	18	.2	3.2	348	272	91	549	7.5	9
Mill Creek at Comstock Park	31	12- 2-52	11.1	7.9	.02	69	25	5.5	1.9	271	40	10	.1	2.9	306	276	53	506	7.9	5
Indian Creek at Walker Dr	30	12- 2-52	5.15	10	.08	75	25	3.0	1.6	282	50	6.5	.1	5.1	320	290	59	528	7.8	7
Indian Creek at Turner St	29	12- 2-52	9.44	8.4	.02	76	22	10	2.2	268	56	14	.2	5.2	334	280	60	550	7.8	7
Plaster Creek at Kalamazoo St	25	12- 1-52	10.2	8.3	.02	82	26	11	3.6	258	83	21	.2	5.9	383	312	100	608	7.8	23
Plaster Creek at U. S. 131	24	12- 1-52	15.1	8.8	.03	83	25	13	4.6	254	85	24	.2	11	391	312	102	622	7.8	12
Buck Creek at Clyde Park Ave	27	12- 1-52	21.1	9.3	.03	92	25	5.8	1.9	232	135	10	.1	5.2	413	334	142	623	7.6	8
Buck Creek at Byron Center Ave	26	12- 2-52	24.9	8.7	.02	92	24	8.8	2.1	227	133	10	.1	4.9	409	328	142	625	7.6	8
Rush Creek at Jenison	32	12- 2-52	30.8	9.2	.02	93	26	7.2	3.0	259	121	7.0	.2	5.9	416	338	127	631	7.4	6

[1] Analyses by Grand Rapids Department of Water Supply.
[2] Average of daily determinations.

SURFACE WATER

Lake Michigan

Lake Michigan is 30 miles west of Grand Rapids and is an almost unlimited source of water of good quality. At present almost all water used by the city of Grand Rapids for its municipal supply is obtained from this source.

The average monthly elevation of the water surface in Lake Michigan, as recorded, has varied from about 577.3 to 583.7 feet above mean sea level at New York. Water must be pumped from this elevation to the summit of the pipeline which is 743 feet above mean sea level and is about 6 miles west of the Grand Rapids filtration plant. The water flows by gravity from the summit to the Grand Rapids filter plant which is about 604 feet above mean sea level.

The water of Lake Michigan is of good chemical quality and the dissolved solids consist principally of calcium and magnesium bicarbonates. The water is moderate in hardness and has an average amount of dissolved solids; its mineral content does not vary appreciably during the year. During 1951—1952, the hardness averaged 136 ppm (parts per million) and the alkalinity 116 ppm. Three analyses of water from Lake Michigan are given in table 1. The average temperature of the water at the Lake Michigan pumping station is 48 F. Average daily temperatures for 1951 are shown in figure 26.

Grand River

Except for the Saginaw River, the Grand River has the largest drainage basin of any stream in Michigan. It drains an area of about 5,570 square miles of which 4,900 square miles lie upstream from Grand Rapids. It is about 300 miles long and has a total fall of more than 500 feet. It rises in the northeastern part of Hillsdale County, flows northwestward, and empties into Lake Michigan at Grand Haven. Its principal tributaries are the Rogue, Thornapple, Flat, Maple, Lookinglass, and Cedar Rivers. (See fig. 4.)

Although most of the basin is flat, some parts can be described as hilly. It contains many lakes and marshes. The soil is predominately clay, although it has an appreciable amount of sand and some loam.

Stage and discharge records have been collected in the Grand River basin at the stations noted and for the periods shown on figure 5.

Although records of discharge are available for the Grand River at Grand Rapids since October 1, 1930, the United States Weather Bureau has obtained records of stage that are nearly continuous since December 1, 1904.

Average Discharge

The average discharge during the 22-year period, 1930—52, was 2,235 mgd (3,458 cfs). Study of the gage-height record obtained by the Weather Bureau at the Pearl Street bridge in Grand Rapids for the period 1905—52, in combination with discharge records collected by the U. S. Geological Survey in 1905 and from 1930 to 1952, indicates that discharge for the 41-year period 1905—52 (intermittent) was 10 to 20 percent higher than that for the period 1930—52. Owing to fragmentary records and serious ice conditions or both, only 41 complete years of the 1905—52 Weather Bureau record were available for study. This difference is not considered unduly large when compared with the variation in annual flow during the period 1930—52. During the first half of the 22-year period the flow averaged 1,745 mgd (2,700 cfs) as compared with 2,725 mgd (4,217 cfs) during the last 11 years. During the 22-year period the annual flow ranged from 814 mgd (1,260 cfs) in 1931 to 4,080 mgd (6,314 cfs) in 1943. The daily flow ranged from 246 mgd (381 cfs) to 26,900 mgd (41,600 cfs). Figure 6 is a hydrograph of daily flow of the Grand River at Grand Rapids during 1938. It shows the fluctuation of flow during a fairly typical year. During the 22-year period the monthly flow ranged from 399 mgd (617 cfs) to 11,600 mgd (17,900 cfs). (See fig. 7.)

Flow Characteristics

Figure 8 shows a flow-duration curve based on daily discharges for the 22-year period, 1930—52. As just explained, the intermittent record for the period 1905—52 showed a discharge 10 to 20 percent higher than that for the period of continuous record, 1930—52. So, an approximate curve showing a 15 percent higher discharge for the period 1905—52 was drawn. The authors believe this approximate curve more nearly represents the flow characteristics of the Grand River at Grand Rapids, and until additional information is available it should be used to solve water-supply problems.

The lowest average flow of the Grand River at Grand Rapids for various length periods are given in figure 9. A point on this curve shows the lowest average flow that was recorded in the corresponding number of consecutive days during the period 1930—52. For instance, one may wish to know the number of consecutive days that the average flow is likely to be less than 325 mgd (503 cfs). By referring to figure 9, it can be seen that from 1930—52 the longest period during which the flow averaged less than 325 mgd was 21 days. This curve may also be used to determine storage requirements for any given outflow rate and for many other uses.

The storage graph (fig. 10) shows the storage required to maintain given rates of flow as high as 650 mgd (1,000 cfs). It is also based on records for the period 1930—52. For example, in order to maintain a flow of not less than 500 mgd (774 cfs) at Grand Rapids, storage of 5,300 million gallons (16,300 acre-feet) would have been required.

Floods

The highest stage reached each year and all peak stages greater than 10 feet that have occurred at Pearl Street during the last 49 years are shown graphically in figure 11. The following table showing the number of occurrences of peaks above certain gage heights was prepared from the data shown in figure 11. The discharge data are from the records of the U.S. Geological Survey.

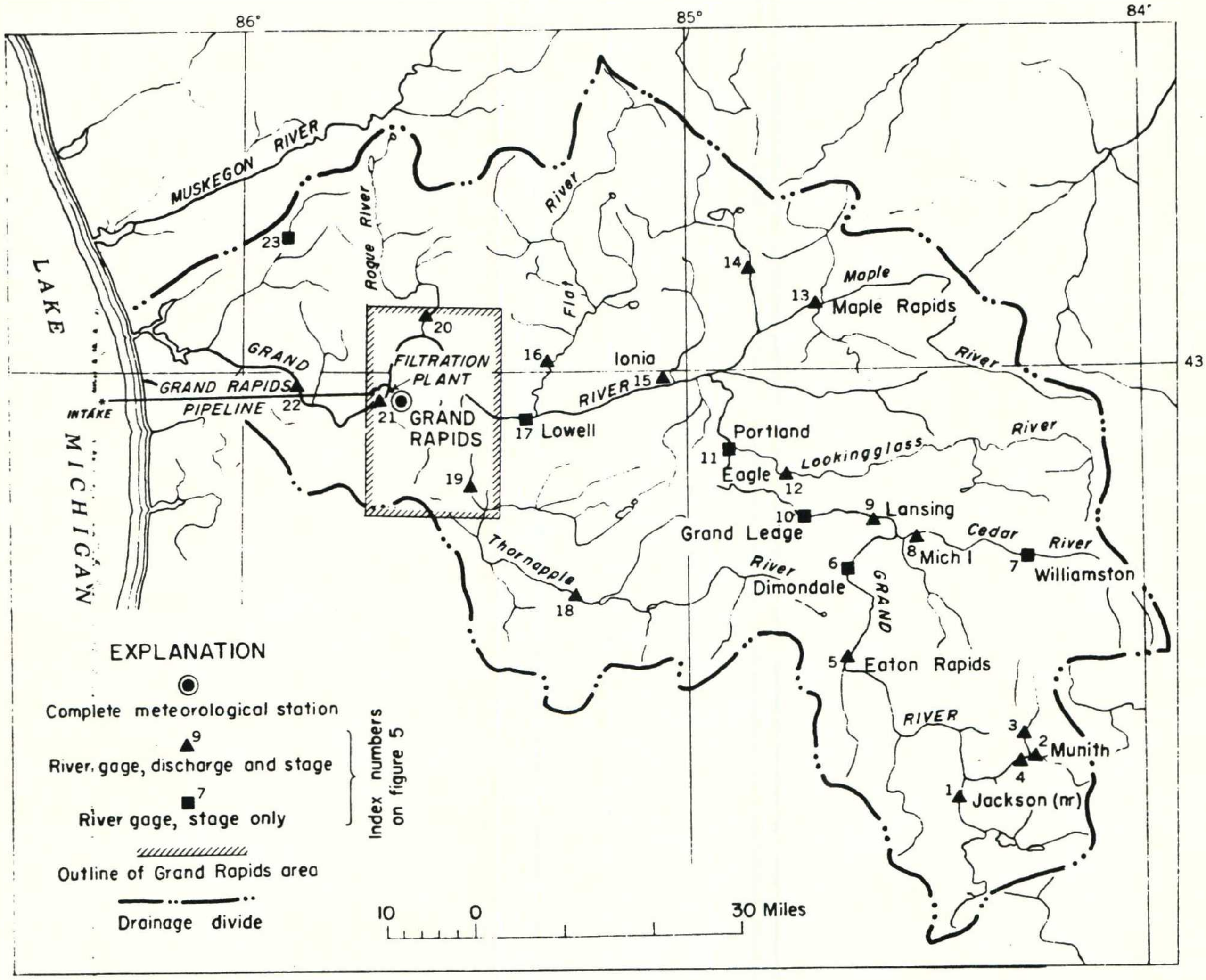
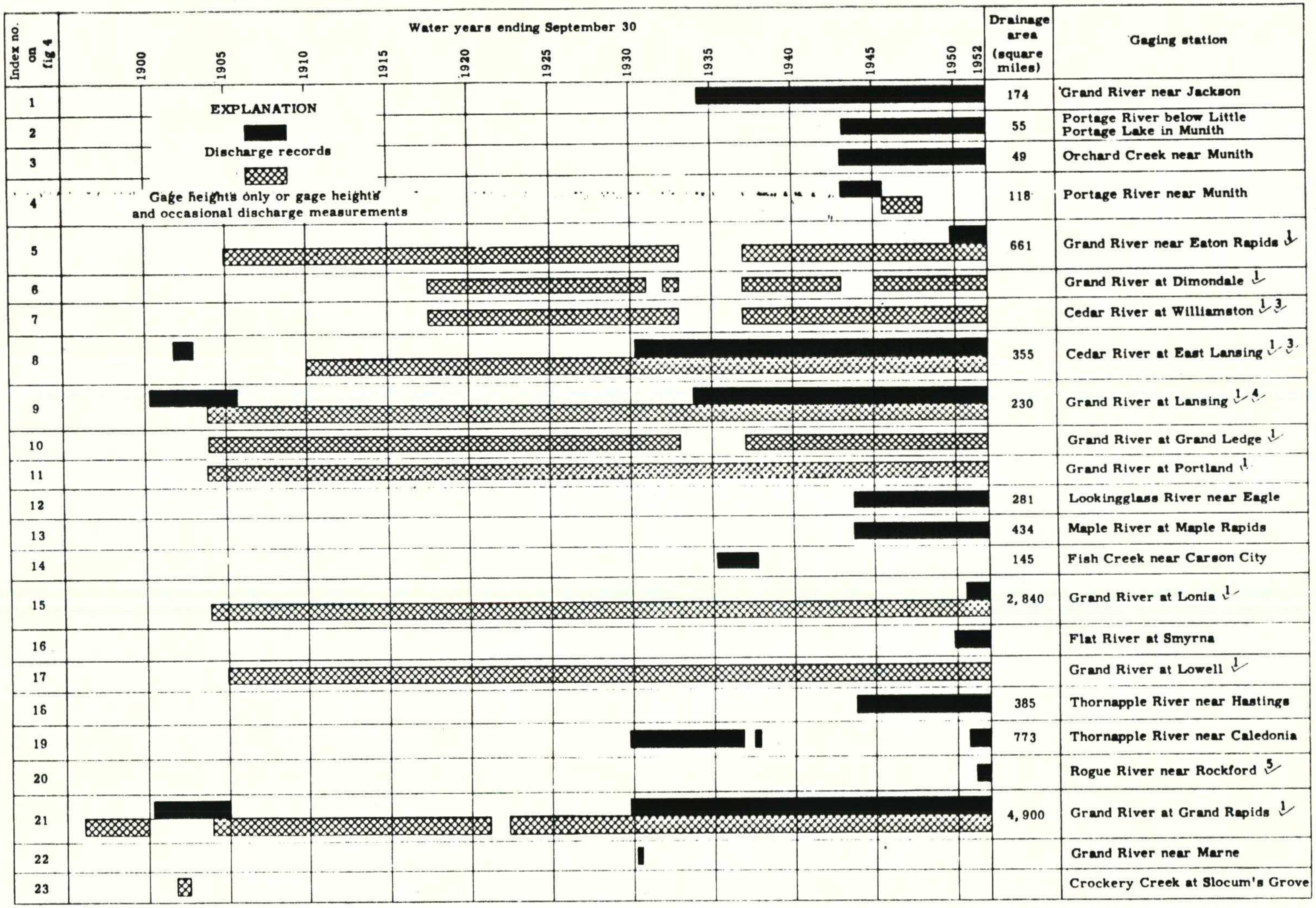


Figure 4. —Map of the Grand River basin.



[1] Records of gage heights include records collected, usually for only a part of each year, by the U.S. Weather Bureau.
[2] Published as "Red Cedar River at Williamston," in Weather Bureau reports.
[3] Published as "Red Cedar River at Agricultural College, Mich.," 1902-03. Published as "Red Cedar River at East Lansing, Mich.," in Weather Bureau reports.
[4] Published as "at North Lansing, Mich.," 1901-06.
[5] Published as "Rouge River" on many maps. Local usage supports Rogue River.

Figure 5.—Duration of records at gaging stations in the Grand River basin.

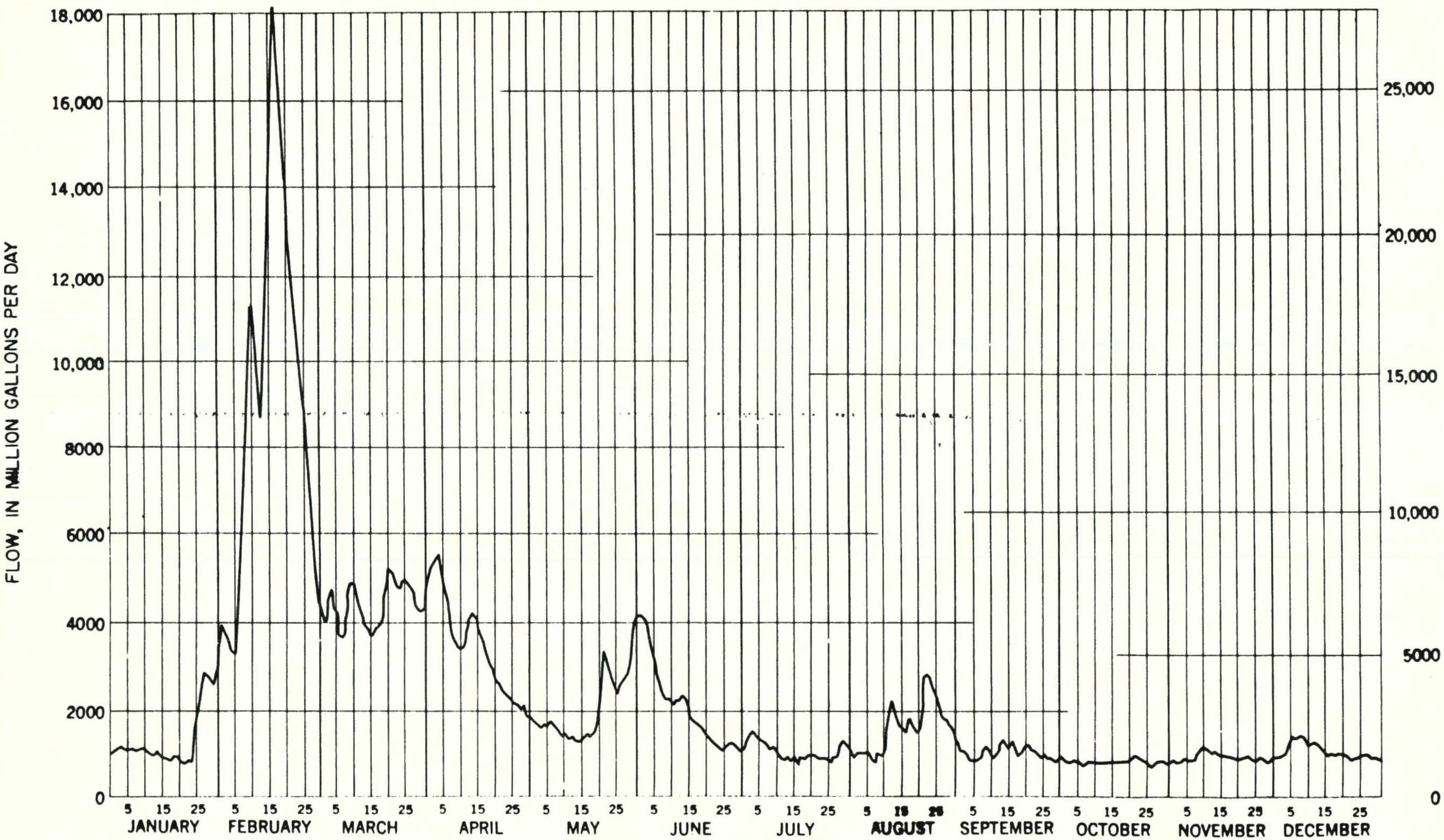


Figure 6.—Daily flow of Grand River at Grand Rapids, 1938.

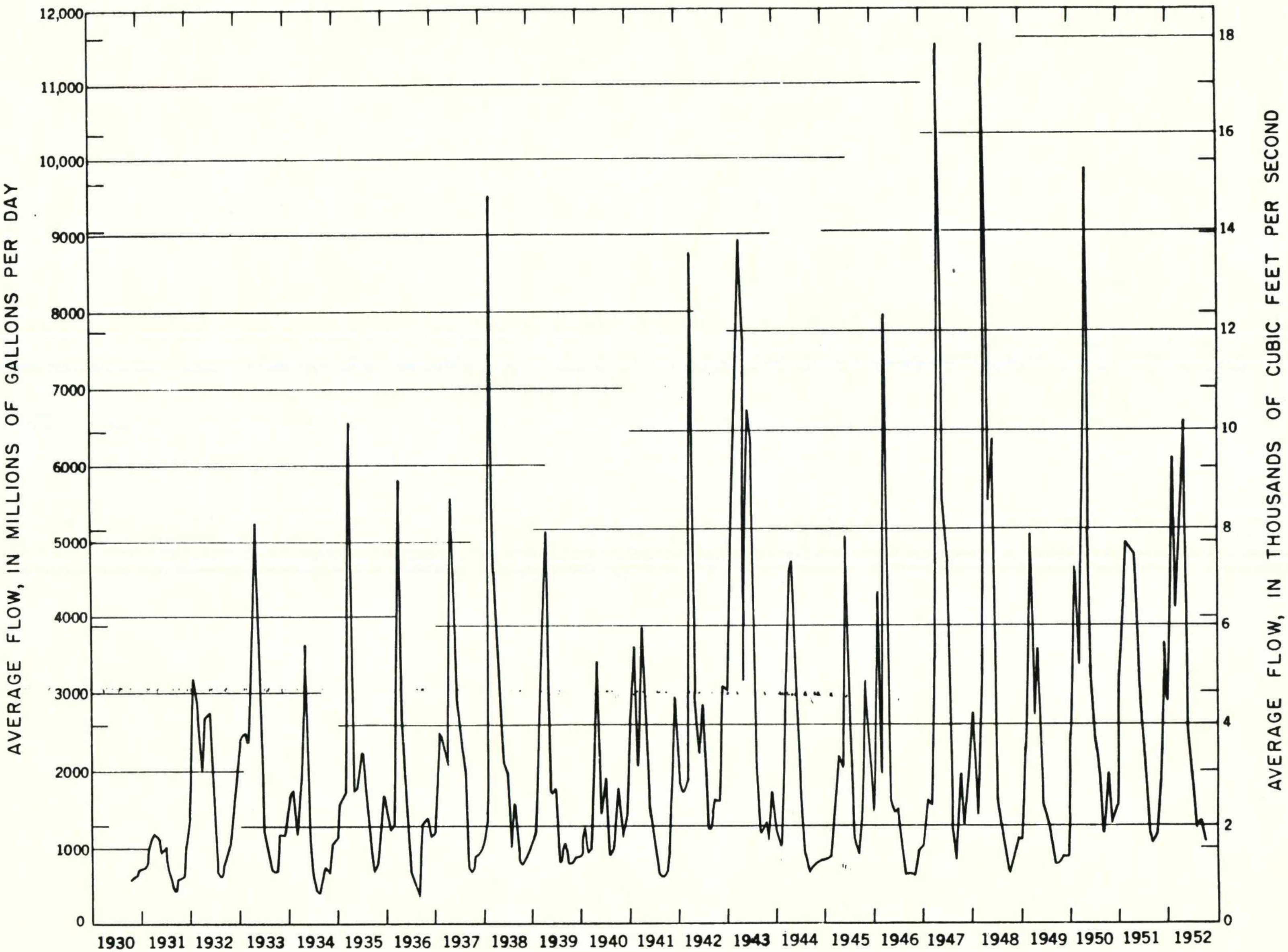


Figure 7. —Monthly flow of Grand River at Grand Rapids, 1930—52.

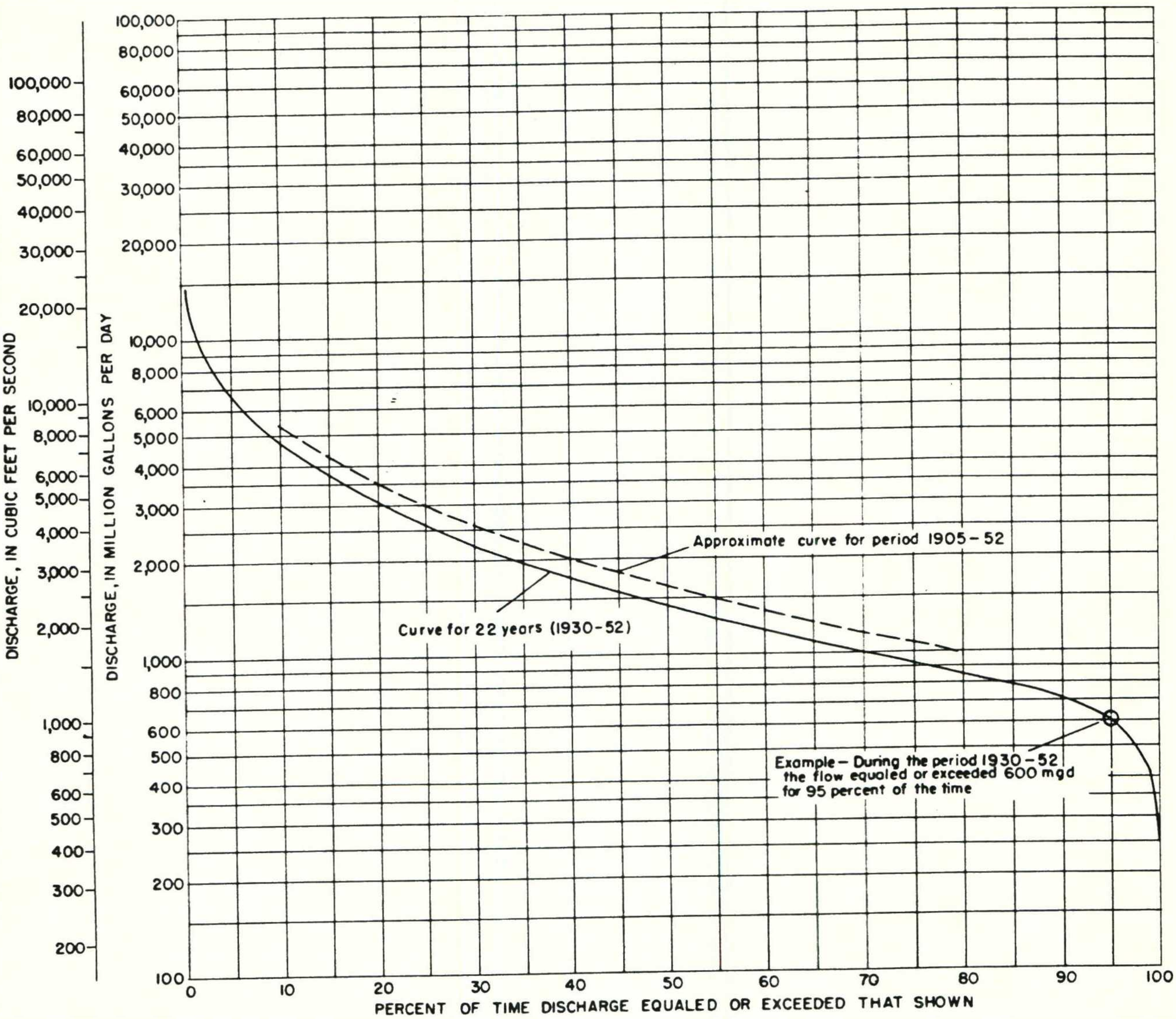


Figure 8.—Duration curve of daily flow, Grand River at Grand Rapids.

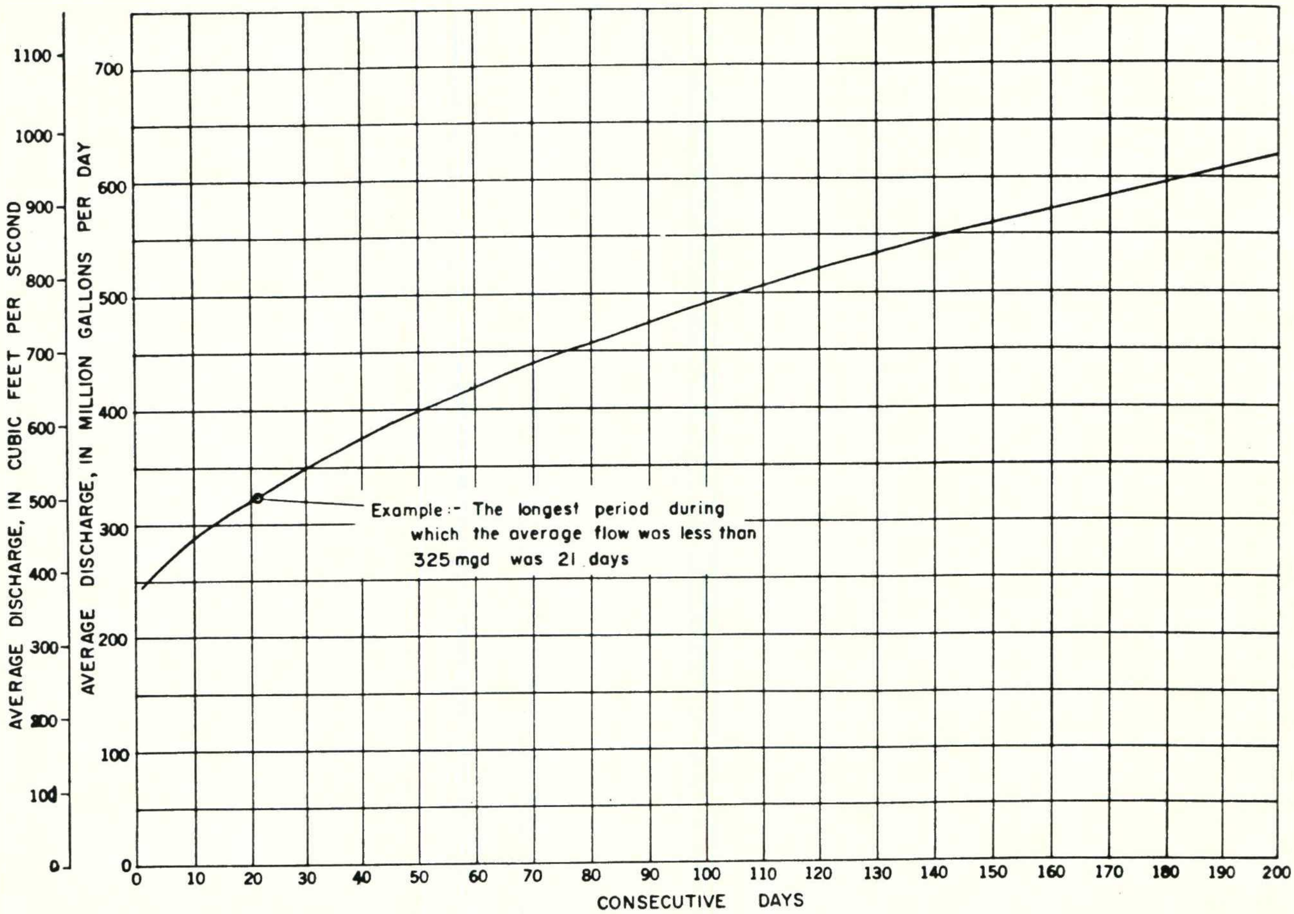


Figure 9. —Lowest average discharge of Grand River at Grand Rapids, 1930—52.

Gage height (feet)	Discharge (cfs)	Number of occurrences
10 or more	15,000 or more	55
12 or more	19,500 or more	34
14 or more	25,000 or more	21
16 or more	32,000 or more	9
18 or more	40,000 or more	4
20 or more	50,000 or more	1

The above data are records of occurrences during the past 49 years and do not necessarily represent the expected magnitude or frequency of future floods. For instance, just because a flood of 50,000 cfs occurred once in the past 49 years, it does not necessarily follow that a flood of the same magnitude may be expected to occur once in the next 49 years. During the next like period it may occur several times or may not occur at all. Studies of the probable magnitude and frequency of future floods, involving the correlation of flood frequencies on an areal basis, can be made to give a more reliable result, but they are beyond the scope of this report. However, because of the fairly long period of record, the 34 floods that exceeded 12 feet may be used as a rough guide to the number that can be expected to exceed 12 feet in the next 49 years. The number of floods that exceeded 14 feet is a far less reliable index of expected occurrences. It can be stated with certainty that floods will occur which will exceed in magnitude anything that has occurred during the past 50 years.

The approximate profiles of the floods of 1904 and 1948 at Grand Rapids are shown in figure 12. These are the two greatest floods recorded there. Profiles are plotted for both the east side and west side of the channel for each flood.

The area in Grand Rapids that was inundated during the flood of 1904 is shown in figure 13. Between 1907 and 1911 floodwalls were constructed, mainly in the downtown area, which have provided a measure of protection against moderate floods.

Chemical Quality

The Grand River water is predominately of the calcium and magnesium bicarbonate types. The water is hard, having an average hardness in excess of 250 ppm. Figure 14 shows the annual maximum, minimum, and average hardness of the water for 10 years (1930—39).

The city of Grand Rapids is under court order to begin construction of a complete sewage treatment

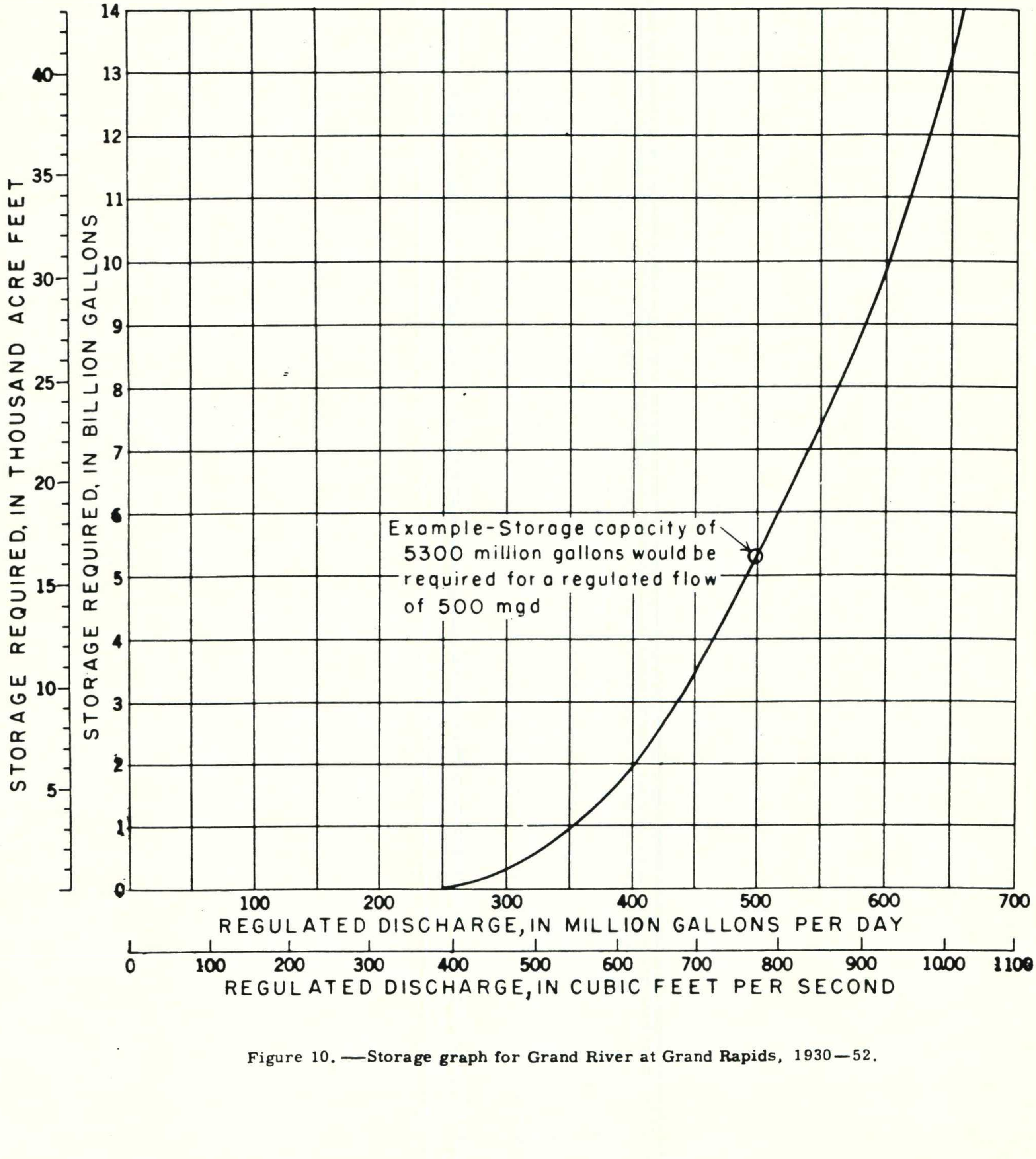


Figure 10.—Storage graph for Grand River at Grand Rapids, 1930—52.

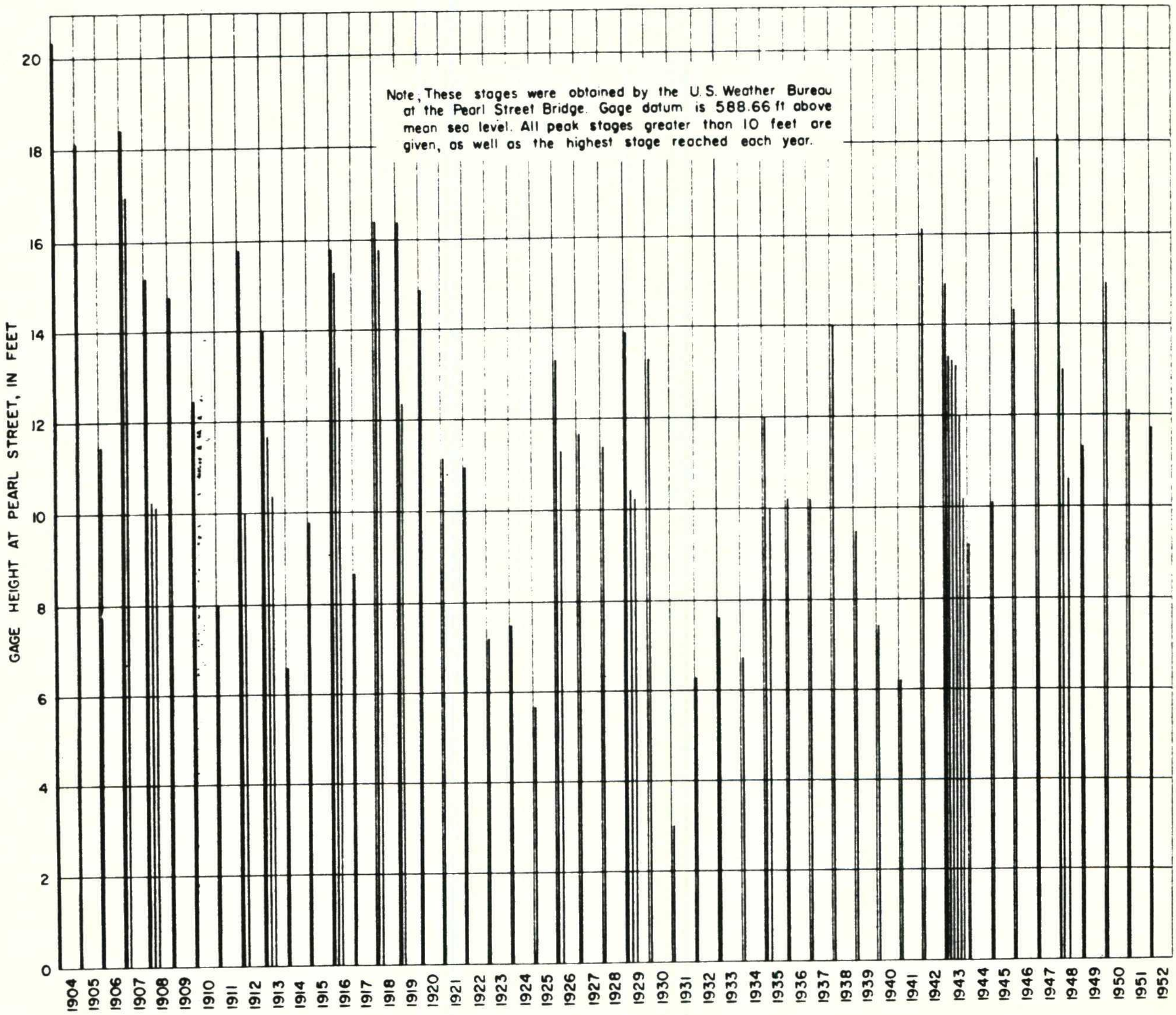


Figure 11. —Peak flood stages on Grand River at Grand Rapids, 1904—52.

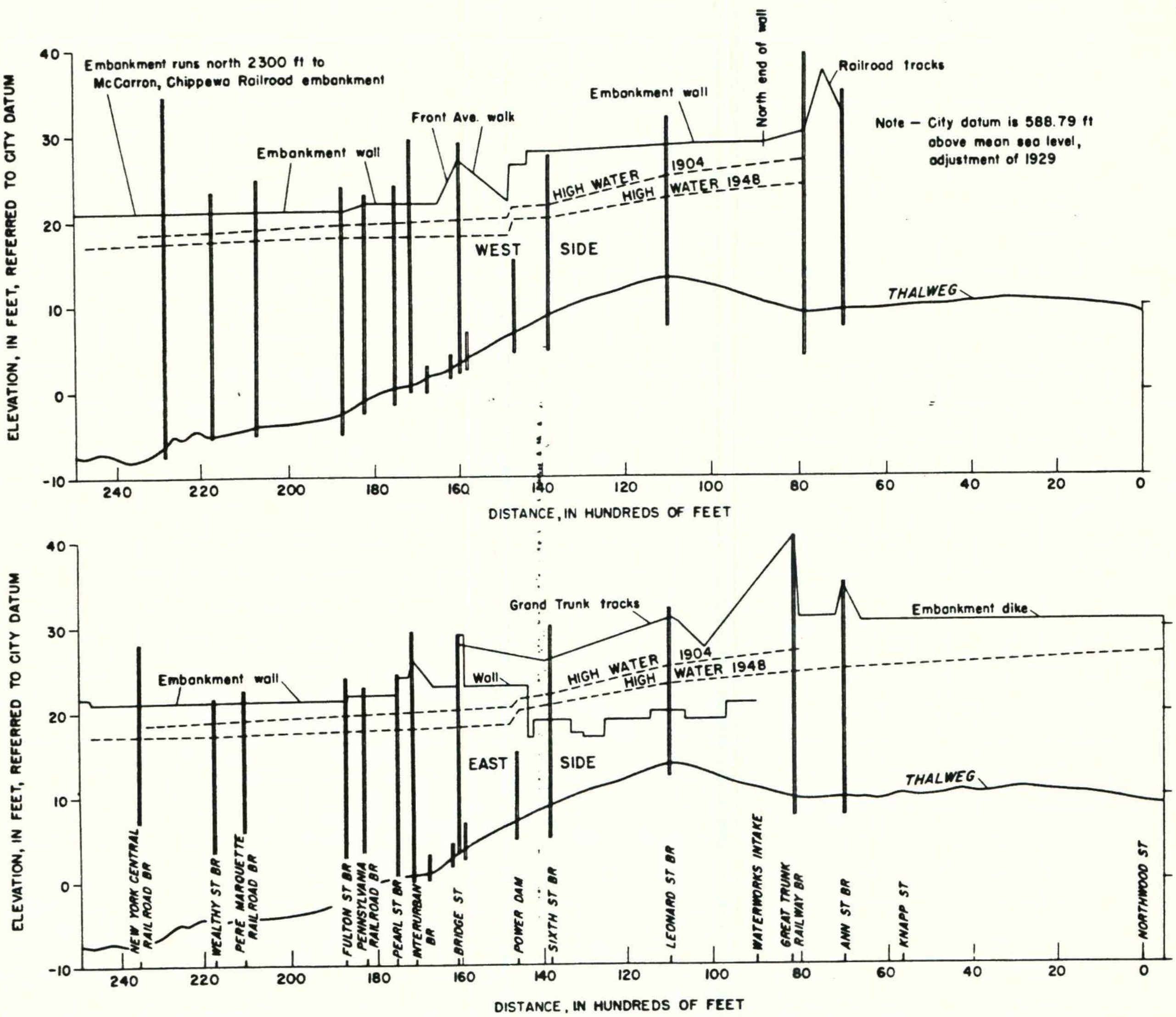


Figure 12.—Profiles of floods of 1904 and 1948 and of protective works, Grand River at Grand Rapids.

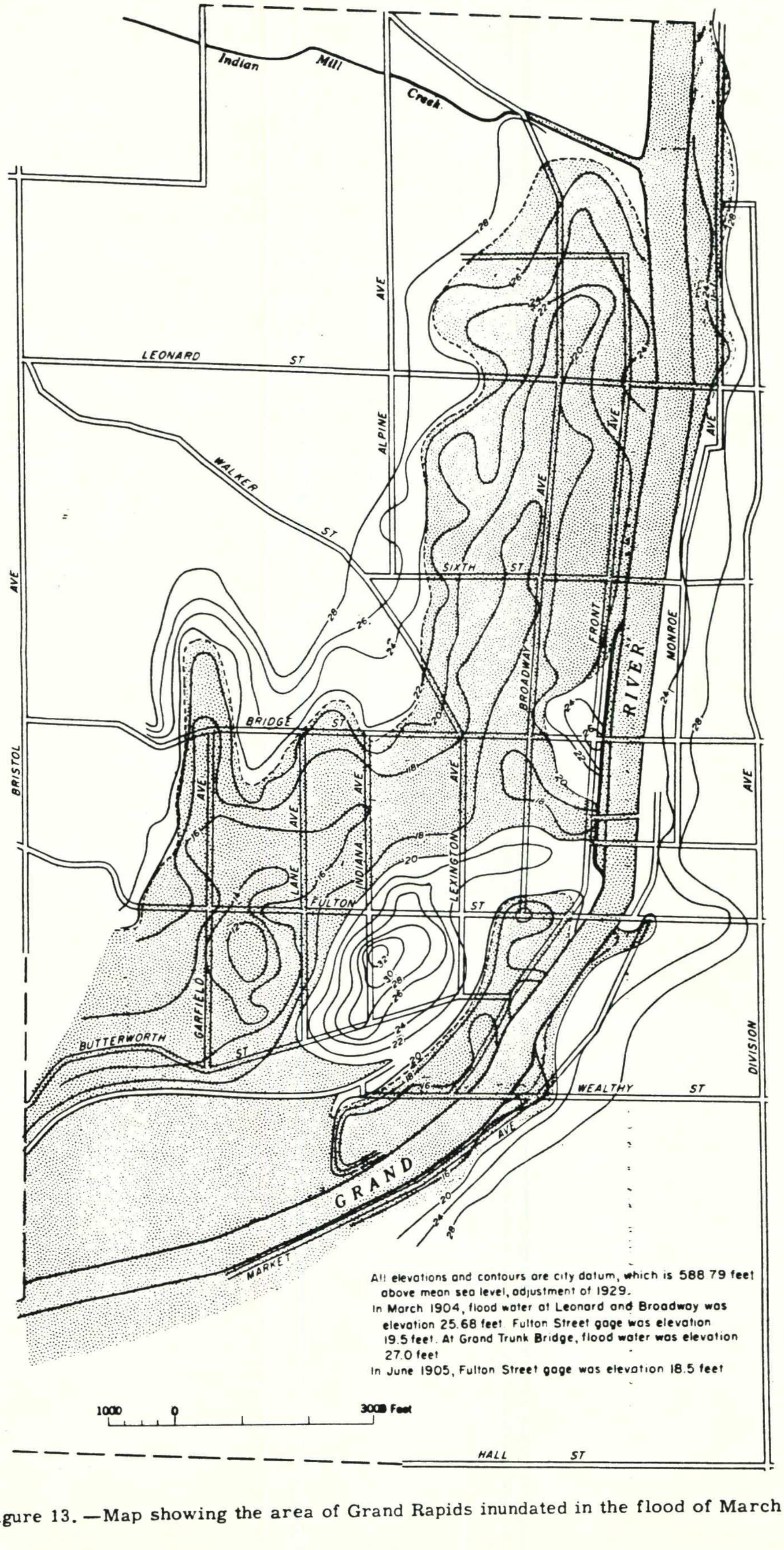


Figure 13. —Map showing the area of Grand Rapids inundated in the flood of March 1904.

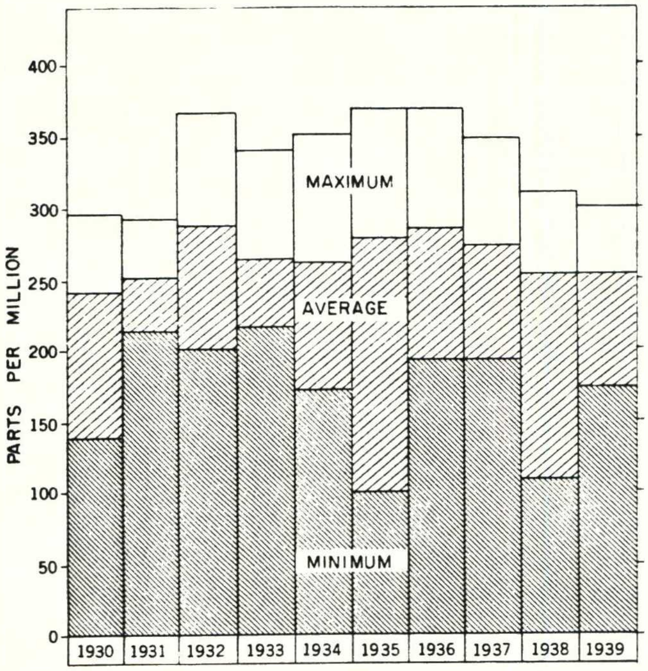


Figure 14. —Maximum, minimum, and average hardness (as $CaCO_3$) of Grand River water at Grand Rapids, 1930—39. (Data from Grand Rapids Department of Water Supply)

plant by January 1954. At present, the effluent from the city's primary sewage treatment plant in southwest Grand Rapids and effluent from a paper mill are discharged into the Grand River. The treatment plant serves Grand Rapids, East Grand Rapids, parts of Wyoming and Paris Townships, and an area on the north adjacent to the city. Highly mineralized ground water used by air-conditioning equipment can be detected in summer in the Grand River where this water drains into the river, but there is no noticeable effect of this drainage at other places in the stream.

The average annual temperature of the Grand River water is 53 F. Table 2 gives the monthly average, annual average, and extremes of water temperature for the years 1930—39.

Tributary Streams

Thornapple River

The Thornapple River, the second largest tributary to the Grand River, has a drainage area of 875 square miles, and empties into the Grand River at Ada, about 9 miles east of Grand Rapids.

Discharge records have been collected at Caledonia from 1930—38 and from 1951 to date. Continuous discharge records are available for the station near Hastings since October 1, 1944. (See fig. 5.)

In figure 15, curve A is a duration curve of daily flows for the Thornapple River near Hastings for the period 1944—52. During this 8-year period the flow of practically all streams in this area was higher than that for the period 1930—52. Therefore, the flow-duration curve for the 8-year period was adjusted on the basis of the relation between the flow of the Thornapple River and that of the Grand River at Grand Rapids. The result of this adjustment (curve B, fig. 15) is the probable flow-duration curve for the Thornapple River for the 22-year period. As previously stated, the flow for the 22-year period 1930—52 was less than the flow for the longer 41-year period (1905—52 intermittent). Therefore, all flows between the 10 and 80 percent duration points would probably be between 10 and 20 percent greater if records for the 41 years had been used. Curve C (fig. 15) is the approximate flow-duration curve for the 41-year period.

A flow-duration curve for the Thornapple River at any point in the Grand Rapids area can be obtained by multiplying the discharge per square mile as shown in figure 15 by the area of the contributing basin. However, the result of such a computation is only approximately correct because the regimen of a stream changes with the area, although this change is usually quite

Table 2. —Temperature of Grand River water at Grand Rapids, in degrees Fahrenheit, 1930—39

[Based on once-daily measurements by the Grand Rapids Department of Water Supply]

	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939
January	34	34	37	35	35	34	33	33	33	33
February	35	36	35	34	34	33	33	33	33	33
March	40	39	37	37	35	39	36	35	42	36
April	49	52	48	49	46	48	45	46	52	44
May	62	60	61	62	65	59	66	62	62	64
June	71	73	74	75	76	67	71	72	72	74
July	75	79	76	78	80	78	78	76	77	78
August	73	74	75	74	74	76	74	78	76	76
September	67	71	67	69	67	66	69	67	65	70
October	53	59	54	54	56	52	54	52	57	56
November	44	49	40	39	46	43	40	41	43	42
December	35	38	35	36	36	34	34	33	35	38
Maximum daily	96	79	83	82	85	83	88	84	82	83
Minimum daily	34	34	33	33	33	33	32	32	32	32
Annual average	53	55	53	54	54	52	53	52	54	54

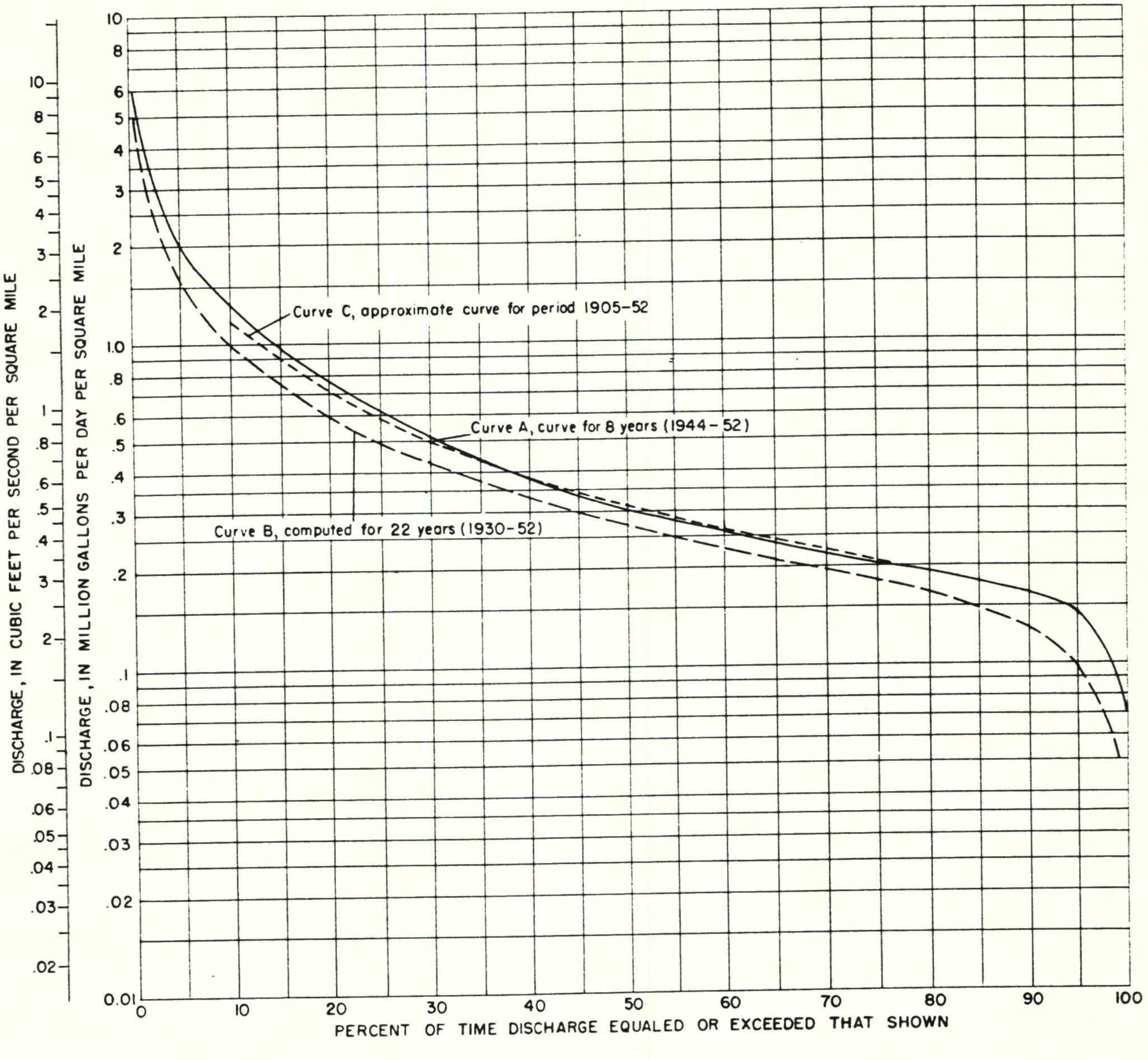


Figure 15. —Duration curve of daily flow, Thornapple River near Hastings.

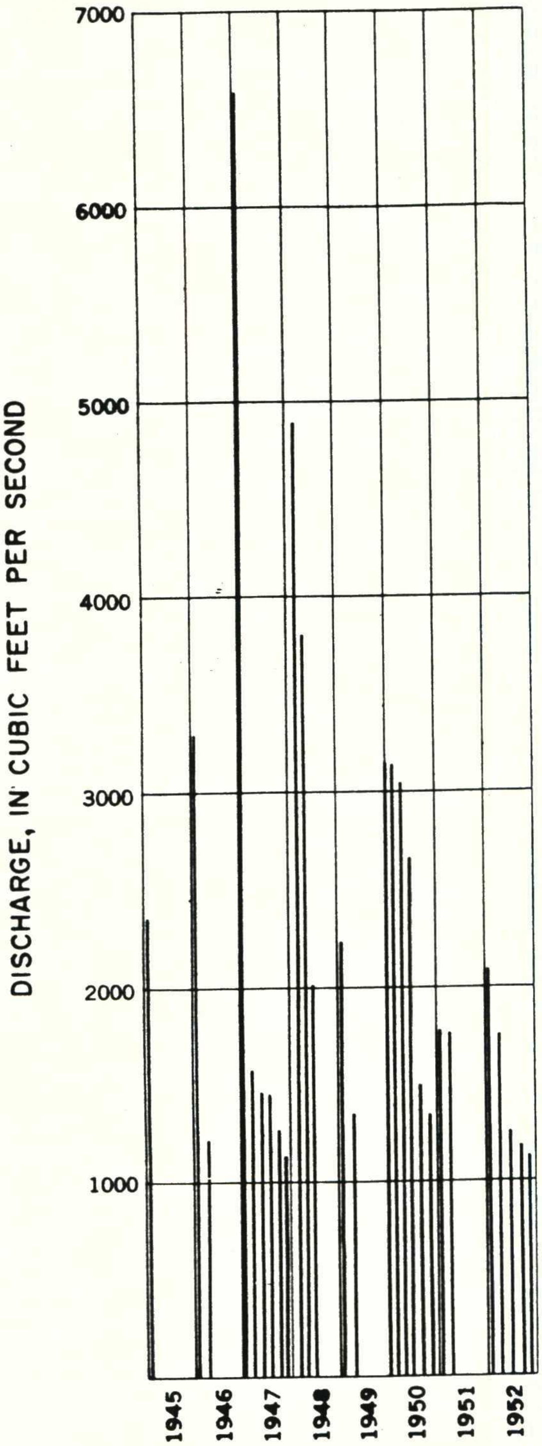


Figure 16. —Flood peaks of 1,000 cubic feet per second or more on the Thornapple River near Hastings, 1944—52.

gradual. The flow of the Thornapple River below Hastings is affected somewhat by powerplant operations.

All floods since 1944 on the Thornapple River near Hastings that have exceeded 1,000 cfs are shown in figure 16. Figure 17 is a hydrograph of monthly flow for the period of record, 1944—52.

An analysis of water from the Thornapple River is given in table 1.

Rogue River

Discharge records on the Rogue River are available only since February 1952 and are therefore inadequate for the determination of its regimen. However, the following tabulation shows the yield of this stream for 8 months of record.

Daily discharge

1952	Maximum (cfs)	Minimum (cfs)	Minimum (mgd)	Mean (cfs)	Mean (mgd)
Feb.	628	195	126	312	202
Mar.	940	210	136	433	280
Apr.	1,160	205	132	411	266
May	800	160	103	279	180
June	260	72	47	144	93
July	645	70	45	233	151
Aug.	465	104	67	219	142
Sept.	267	92	59	147	95

An analysis of water from the Rogue River is given in table 1.

Small Streams

There are no continuous records of daily discharge on the small tributaries of the Grand River in this area. However, a few discharge measurements were made on these streams in 1952. (See table 3.) Based on these discharge measurements and records for streams nearby, the low-flow characteristics of the small streams have been computed and the results are shown in table 4.

Chemical Quality

The streams tributary to the Grand River in the Grand Rapids area appear to be similar in chemical character. The waters are the calcium and magnesium bicarbonate types and contain varying amounts of sulfate. Chemical analyses of water from these streams are given in table 1.

Pollution is present in varying degrees in the tributary streams. The Rogue River contains paper mill and tannery wastes and treated effluent from the city

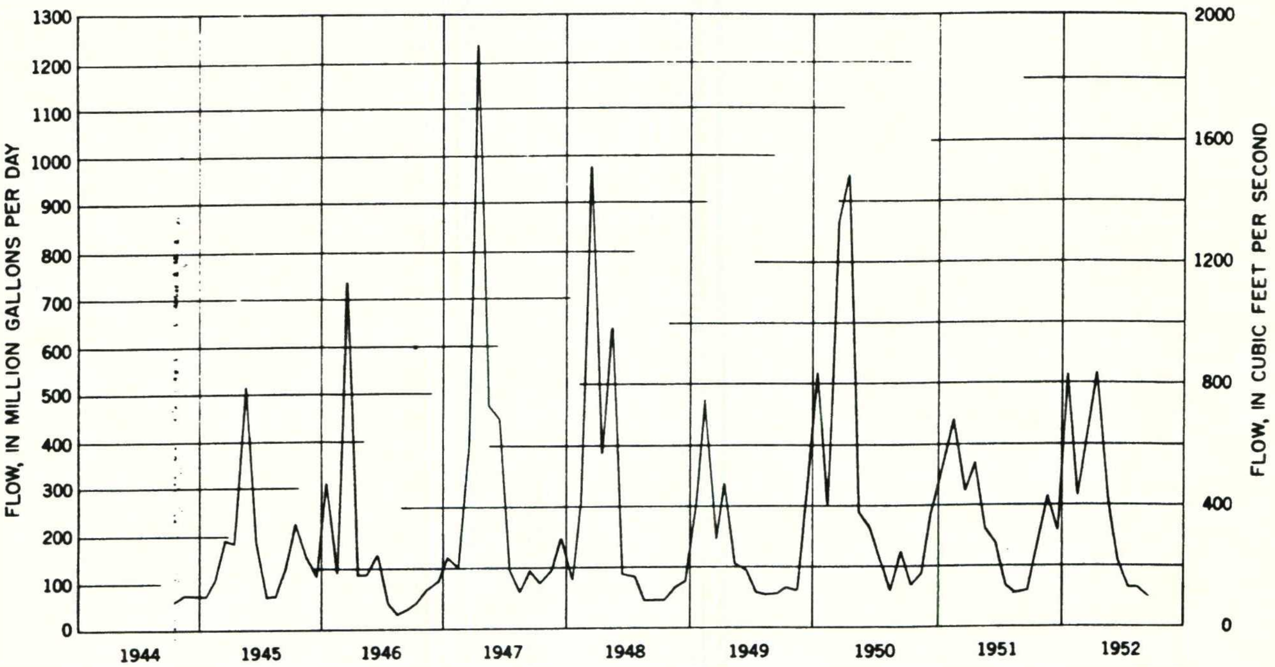


Figure 17. —Monthly flow of the Thornapple River near Hastings, 1944—52.

Table 3.—Discharge measurements of streams tributary to the Grand River in the Grand Rapids area, 1952

Stream and location	Index no. on plate 1	Drainage area (square miles)	Discharge, in cubic feet per second										
			Apr. 21	Apr. 22	May 5	May 6	June 24	Sept. 8	Sept. 9	Oct. 14	Oct. 15	Dec. 1	Dec. 2
Plaster Creek at													
U. S. 131............	24	48.0	25.1	....	12.5	.....	9.95	8.00	....	5.72	......	15.1	......
Kalamazoo St........	25	43.9	24.2	....	8.67	.....	....	4.02	....	3.11	......	10.2	......
Buck Creek at													
Byron Center Ave..	26	44.2	38.7	....	....	28.9	21.9	16.6	....	15.1	......	....	24.9
Clyde Park Ave.....	27	40.0	39.2	....	23.4	......	....	12.5	....	12.1	......	21.2	......
Buck Creek tributary at Fisher Station...	28	6.4	6.76	....	3.64	......	....	1.34	....	.91	......	2.13	......
Indian Creek at													
State Route 37 (near Turner St.).	29	16.5	12.6	....	....	9.16	....	....	6.67	....	6.23	....	9.44
Walker Dr............	30	13.0	9.09	....	....	6.15	3.83	....	4.36	....	3.87	....	5.16
Mill Creek at													
Comstock Park......	31	19.7	18.0	....	....	10.9	8.86	....	9.27	....	7.50	......	11.4
Rush Creek at													
Jenison................	32	61.4	......	52.3	....	31.7	....	23.6	....	19.0	....	......	30.8

of Rockford. However, treatment facilities for the tannery wastes are under construction and Rockford has been ordered to provide improved control of its sewage pollution by 1954. Buck Creek contains some sewage and treated effluent. Rush, Mill, and Plaster Creeks and upper Indian Creek contain very little waste discharge. Indian Creek, below Walker Drive, receives some industrial and domestic wastes.

GROUND WATER

Occurrence

Ground water in the Grand Rapids area occurs in both bedrock and unconsolidated glacial-drift deposits and is used by practically all the population and industries outside the area served by the cities of Grand Rapids and East Grand Rapids. Thus, ground water is a valuable and essential natural resource in the Grand Rapids area.

The quantity and quality of the ground water available are dependent on the geology. Therefore, some knowledge of the geology is essential to an appraisal of the water resources.

The materials comprising the earth's crust contain many pores and other openings of various shapes and sizes. Water is collected and stored within these pores which are generally connected so that water can move from one to another. Formations containing interconnected pore spaces that are saturated with water and provide water to wells in appreciable quantity are called aquifers.

Ground water is a renewable resource and is generally moving slowly from areas of intake to areas of discharge. The amount of water that can be obtained depends on the permeability of the aquifer, the volume of water in storage, the amount of replenishment, and the quantity of natural discharge that can be salvaged. The storage capacity, transmission capacity, and manner in which ground water is replenished vary from aquifer to aquifer. If an aquifer is used for a long time, discharge cannot exceed recharge (replenishment). When discharge exceeds recharge, the difference must be supplied from storage, and the water level falls. Withdrawals in excess of recharge can continue only as long as water in storage is available.

Ground water may occur under either water-table or artesian conditions. Under water-table conditions, the water is unconfined and the upper surface of the saturated zone is called the water table. Under artesian conditions, the water is confined under pressure between relatively impermeable strata. The hydrostatic pressure in the confined part of the aquifer is

Table 4.—Probable duration of low flows of small streams in the Grand Rapids area, 1944—52

Stream and location	Discharge equaled or exceeded (million gallons per day per square mile)				Drainage area (square miles)	Index no. on plate 1
	70 percent of time	80 percent of time	90 percent of time	95 percent of time		
Buck Creek at Byron Center Ave.	0.29	0.26	0.23	0.22	44.2	26
Indian Creek at Walker Dr.........	.22	.19	.17	.16	13.0	30
Mill Creek at Comstock Park.....	.30	.28	.26	.24	19.7	31
Plaster Creek at U. S. 131........	.13	.10	.08	.07	48.0	24
Rush Creek at Jenison...............	.26	.24	.22	.20	61.4	32

caused by the higher levels of water in the intake area. If this pressure is great enough to raise the water in a well to a point above land surface, water will flow from the well without pumping. It is important to remember that an artesian aquifer is at all times full of water, even during the time that water is being removed from the aquifer. However, it is possible to pump enough water from an artesian aquifer to draw the water level below the top of the aquifer, so that locally water-table conditions exist during pumping.

In general, the aquifers in the Grand Rapids area are recharged by precipitation that falls within the area. In those places where ground water occurs under water-table conditions, the source of replenishment is generally in the immediate area. The water level rises in response to recharge from precipitation. Declines in water level occur because of evapotranspiration, drainage to streams, and discharge by wells. Figure 18 shows the rise and fall of water level in a typical well, no. KeGV 13 at Grandville.

Water-Bearing Formations

Ground water occurs throughout the Grand Rapids area in both the glacial drift and in consolidated rocks (bedrock) which underlie the drift.

Bedrock

The bedrock formations that crop out in the area are entirely of sedimentary origin; that is, they were formed from sands, clays, or limy muds that were deposited in the shallow but vast inland seas that covered this area in Mississippian and Pennsylvanian times. Older sedimentary formations underlie the Mississippian rocks but they contain water in small quantities or water that is too highly mineralized for most uses except as a possible source of minerals.

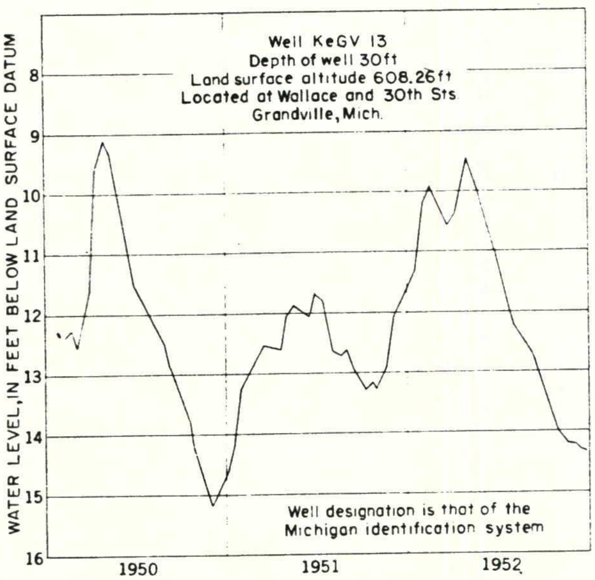


Figure 18. —Water level in an observation well in Grandville, 1950—52.

Therefore, they will not be considered in the report. The bedrock in the area is covered nearly everywhere by glacial drift.

In the Grand Rapids area the rocks that form the bedrock surface beneath the drift are, from oldest to youngest: the Marshall formation, the Michigan formation, and the Bayport limestone, all of Mississippian age; the Parma sandstone and a very small area of outcrop of Saginaw formation, both of Pennsylvanian age. The bedrock formations are exposed along the Grand River in the southern part of Grand Rapids and at points in Wyoming, Paris, Gaines, and Walker Townships.

The bedrock surface beneath the glacial drift was eroded into ridges, valleys, and plains, having topographic features somewhat similar to those we see today. However, it does not necessarily follow that bedrock elevations are beneath present surface elevations, or that bedrock depressions will underlie surface depressions. Only exploration will reveal the bedrock surface. The regional bedrock topography is shown in figure 19.

The regional dip of the bedrock is to the northeast and is about 27 feet to the mile. A generalized columnar section, including a brief description of the rocks of the area is shown in table 5. Two generalized sections showing the dip and position of the bedrock in relation to the overlying drift are shown in figure 20. The location of these sections is shown on plates 2 and 3.

Coldwater shale. —The Coldwater shale lies deeper than the oldest formation outcropping in the area and is the oldest rock considered in this report. However, this formation offers little or no opportunity for development of wells, as the formation is relatively impermeable in this area and any water that might be obtained would undoubtedly be highly mineralized.

Marshall formation. —The Marshall formation lies immediately above the Coldwater shale and is the only bedrock formation in the area that yields large quantities of water. The formation is composed almost entirely of white, red, or pink sandstone which is relatively permeable and is an important water-bearing formation in the area. The formation contains a shaly facies that separates the formation into an upper and lower part. (See fig. 20.) The upper part, named the Napoleon sandstone member, seems to be the more permeable and is the main source of water for many industrial wells in the Grand Rapids area. Wells yielding as much as 1,000 gpm have been developed from the Marshall formation. These waters are generally used for cooling, refrigeration, washing, and various other uses. Outside of the industrial area, most of the wells are for domestic supply; and they obtain larger quantities of better quality water from the overlying drift.

Water samples from the Marshall formation were collected and analyzed to provide data on the chemical character of these waters and to illustrate the variations in chemical quality throughout this area. It has long been recognized that water in the Marshall formation becomes more mineralized downdip (Cook 1913, p. 56).

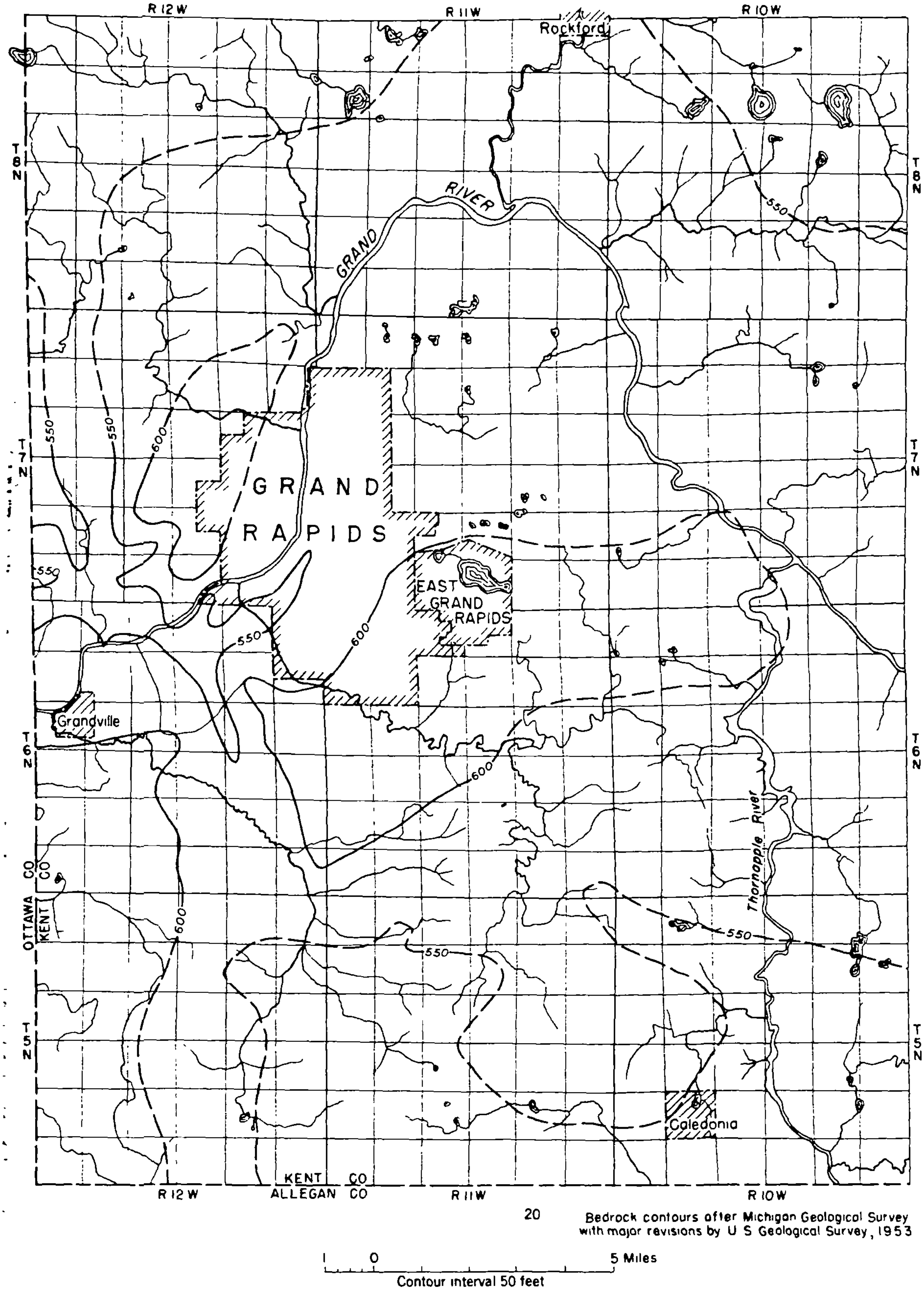


Figure 19. —Topography of the bedrock surface of the Grand Rapids area.

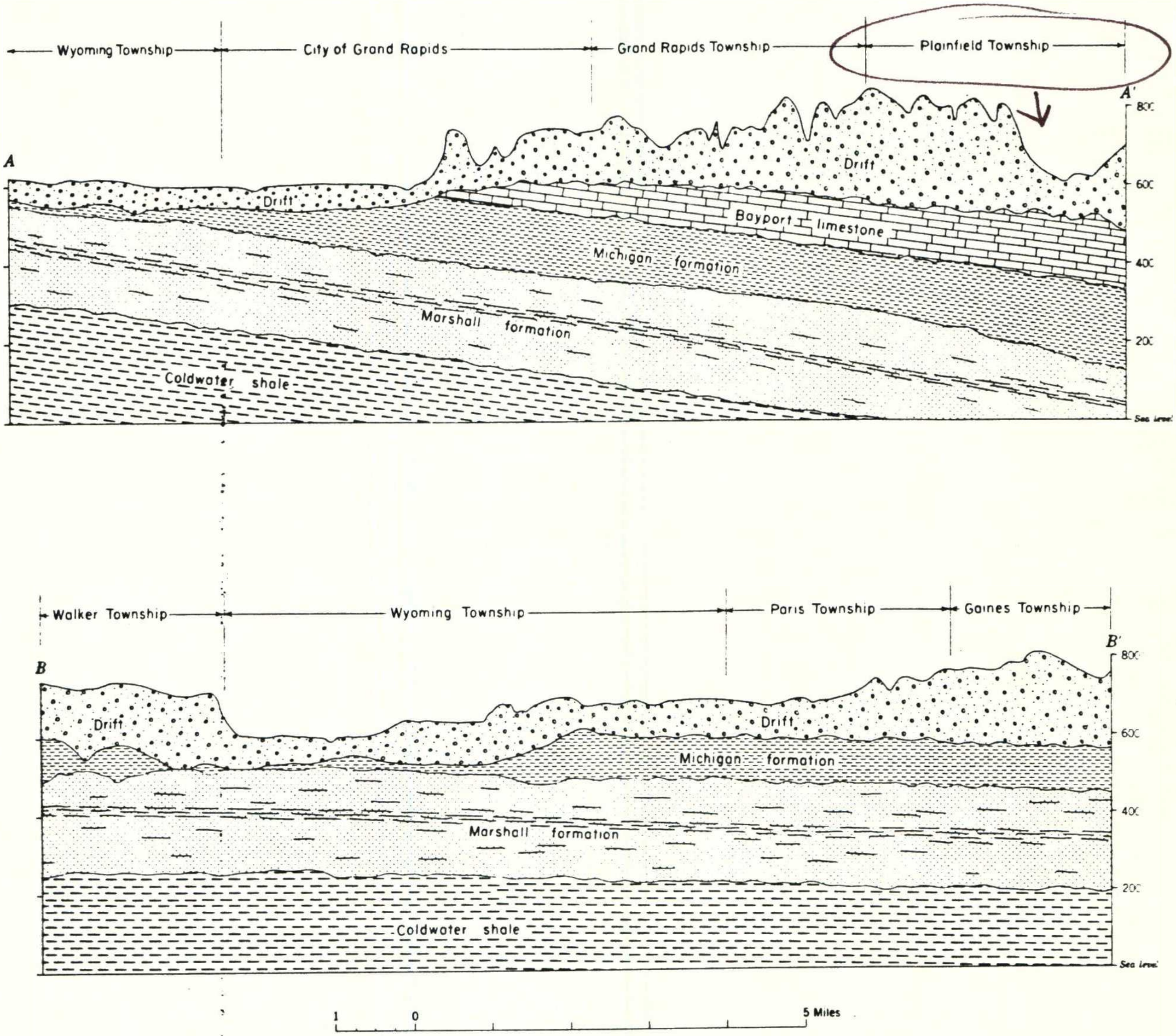


Figure 20.—Generalized geologic sections, A-A' and B-B'. (See pls. 2 and 3 for location of sections.)

Table 5.—Water-bearing properties of the geologic formations in the Grand Rapids area

System		Series	Formation	Character of material	Approximate thickness (feet)	Water-bearing properties
Quaternary		Recent and Pleistocene	Drift	Sand, gravel, clay, and till.	0-300	Yields small to large supplies. Generally the water is hard, with varying mineralization, but acceptable for most uses. Is source for most wells in the area.
Carboniferous (systems)	Pennsylvanian		Saginaw formation	Sandstone, sandy shale, limestone, coal.	0-100	Yields small supplies of potable water.
			Parma sandstone	Sandstone, conglomerate.	0-200	Yields small supplies of potable water.
	Mississippian		Bayport limestone	Limestone, sandy limestone, sandstone.	0-100	Yields small supplies of potable water.
			Michigan formation	Shale, limestone, gypsum, dolomite, sandstone.	0-250	Contains small quantities of hard, calcium sulfate type water.
			Marshall formation	Sandstone, red and white, some shale and siltstone.	100-300	Generally, yields large quantities of water which is potable at the outcrop and for a short distance downdip; becomes increasingly more mineralized downdip.
			Coldwater shale	Shales and thin lenses of sandstone, dolomite, and siltstone.	500-800	Locally, lenses may yield small quantities of highly mineralized water.

All of the wells finished in the Marshall formation at Grand Rapids produce water that is very hard and moderately to very highly mineralized. Many wells produce noticeable amounts of hydrogen sulfide gas. The amount of mineralization and the chemical character of the water both change progressively across the area. Proceeding from south to north through Grand Rapids, the degree of mineralization becomes progressively higher (fig. 21). The reacting values of the various constituents, or concentration expressed in equivalents per million, were used in preparation of the bar diagrams in figure 21. Equivalent per million (epm) is the number of unit equivalent weights of an ion contained in 1 million unit weights of the water. An equivalent weight of a substance is defined as the weight that is exactly equal in reacting capacity to one atomic weight (1.0080 grams) of hydrogen. Equivalents per million are useful in expressing chemical combinations as well as in expressing analyses graphically, since one equivalent of a cation, such as calcium, will combine with exactly one equivalent of an anion, such as chloride, to form one equivalent of a compound such as calcium chloride. The northernmost well sampled (no. 1) had very highly mineralized water, the concentration being that of a weak brine. The dissolved solids content was 12,660 ppm and the hardness 3,280 ppm. The water from well 2, about 1 mile south of well 1, contained 9,642 ppm dissolved solids and had a hardness of 2,397 ppm. In both of these waters, the predominant constituent was sodium chloride, more than 90 percent of the salts being chlorides. Well 3, in the downtown area, yielded a distinctly different type of water from that drawn from the Marshall formation. This sample had dissolved solids of 2,134 ppm, hardness of 1,160 ppm, and was predominately calcium sulfate in chemical character. South of this point the analyses showed lesser concentrations of dissolved solids and a continuation of the calcium sulfate character of the water. Well 6, just south of Grand Rapids, produced water that contained 895 ppm of dissolved solids and that had a hardness of 580 ppm. Analyses of water samples from the Marshall formation are included in table 6.

Winchell (1861, p. 91) stated that he thought the source of the brine in the Grand Rapids area was from the Michigan salt group. (The Michigan salt group was composed mostly of what is now known as the Michigan formation.) He also stated that the water in the Napoleon member of the Marshall formation was fresh. However, based on various other data which he presents in his report, it appears that the term "fresh water" as he used it, was only a very relative term and that the water found in the Napoleon member was originally moderately mineralized. Rominger (1876, p. 93) after studying Winchell's data stated:

"Borings in the western central portion of the peninsula, at Grand Rapids and vicinity, described by Prof. Winchell's report of 1861, need no repetition here. In all of them, the Waverly group is found to be the repository of the brine. The borings never were

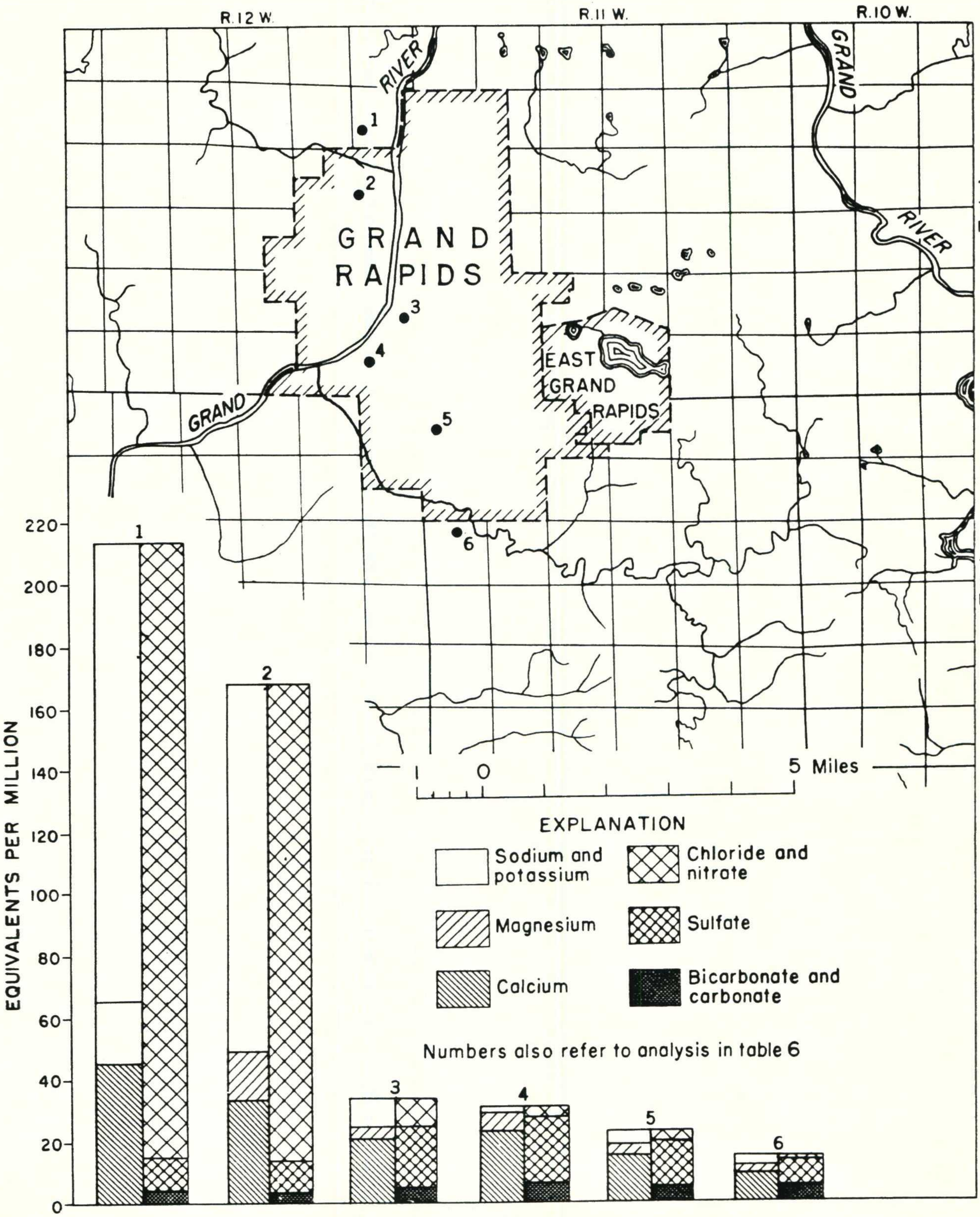


Figure 21. —Composition of water from selected wells in the Marshall formation in the Grand Rapids area.

Table 6. —Chemical quality of water from selected wells in the Grand Rapids area

[Chemical results in parts per million]

Index no.[1]	Owner	Formation	Depth (feet)	Date	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color
1	General Motors Plant No. 2	Marshall formation	300	1-21-53	11	7.8	0.00	920	238	3,380	49	219	492	7,020	.....	......	12,660	3,280	3,100	19,170	7.1	1
2	Ruster Dairy Co.	Marshall formation	300	1-21-53	10	13	....	654	186	2,700	43	187	456	5,460	.....	......	9,640	2,400	2,240	14,980	7.0	......
3	Ellis Brothers Produce Co	Marshall formation	300	1-22-53	14	3.4	.00	400	39	199	7.9	242	974	272	0.5	0.5	2,130	1,160	960	2,670	7.3	8
4	Keeler Brass Co.	Marshall formation	250	1-21-53	14	.79	.00	460	61	56	3.0	358	1,040	88	.1	.1	2,010	1,400	1,100	2,380	7.0	2
5	Bordens Dairy Co.	Marshall formation	304	1-21-53	17	.97	.00	296	36	112	6.5	276	691	117	.4	.0	1,470	890	660	1,890	7.0	3
6	Heckman Biscuit Co.	Marshall formation	315	1-21-53	17	1.7	.00	186	27	56	3.0	300	362	48	.4	.0	895	580	334	1,220	7.0	3
7	Keeler Brass Co.	Michigan formation	50	1-21-53	14	.72	.00	452	63	47	2.3	362	1,010	83	.1	.1	1,960	1,390	1,090	2,230	7.1	6
8	E. C Mandler	Bayport limestone	57	1-21-53	8.4	.07	.00	79	28	8.1	5.7	267	51	29	.0	28	378	312	93	649	7.3	0
9	Knapp Avenue Creamery Co.	Drift	48	1-21-53	8.2	.07	.00	83	22	6.1	1.7	273	48	21	.0	9.8	339	300	74	584	7.2	0
10	Corduroy Rubber Co.	Drift	86	1-21-53	16	1.3	.00	108	34	9.7	1.7	381	101	7.0	.1	.2	474	410	97	753	7.1	5
11	East Grand Rapids Municipal Well	Drift	138	1-20-53	20	1.7	.00	101	31	8.7	1.8	420	37	10	.1	.0	417	380	35	695	7.1	15
12	Doehler-Jarvis Corp.	Drift	30	1-21-53	2.4	.17	.00	31	12	5.0	1.3	128	24	7.0	.8	.6	148	129	22	277	7.2	10
13	Pure Oil Co.	Drift	30	1-22-53	6.9	.07	.00	172	34	50	2.0	248	341	84	.1	.9	850	570	366	1,240	7.3	3
14	R. Miedma (Paris Township)	Drift	97	1-22-53	16	1.5	.00	224	51	46	2.4	272	614	3.5	.4	0	1,150	770	546	1,410	7.8	3
15	Perfect Machine and Tool Co.	Drift	22	1-21-53	11	.04	.00	96	26	22	1.2	298	63	32	.0	35	447	348	102	748	7.6	1

[1] Numbers refer to location of wells in figures 21 and 23.

carried deep enough, under the false impression that the salt brine had its site in the higher gypsiferous rock series, in the Michigan salt group of Winchell."

The Waverly group of Rominger (1876) as used above was composed mostly of what is now known as the Marshall formation. In other words, the Napoleon member also contained mineralized water. The Napoleon member, owing to its greater permeability and better circulation could, before pumping, have contained water that was relatively less mineralized than water from formations above and below it.

The increased mineralization of water in the Napoleon member has been attributed to the fact that many old brine wells were not properly sealed. This would make it possible for brines to flow from above and below into the Napoleon. Although some of the contamination has probably come about as a result of this, it seems that it was only one reason for increased mineralization, for the failure to plug these old brine wells probably resulted in only a local intermingling of waters from the three different horizons. However, increasing pumping since the turn of the century and particularly in the last two decades, and the resulting cone of depression, have probably caused the more mineralized water downdip to migrate updip toward the center of heavy pumping. In addition, pumping probably also increased the leakage from the old wells.

Regardless of whether there was relatively fresh water in the Napoleon member of the Marshall formation before the drilling of the unplugged wells, the fact is that today water in the Marshall formation is moderately to highly mineralized.

This chain of events is pointed out because a belief exists that heavy pumping in the area would eventually result in the removal of the mineralized water from the aquifer. The dissolved solids have increased rather than decreased in several wells where this has been attempted. Although there is a lack of data concerning the extent of the area of high salinity, it would be expected that heavy pumping from the Marshall formation would cause the migration of highly mineralized water updip and thus would aggravate the situation rather than improve it. At the present time evidence is insufficient to prove that the contaminated area is growing. The areas of extreme mineralization have probably adjusted themselves to new positions of equilibrium as a result of pumping.

Therefore, it seems that the greater part of the increased mineralization has come about as a result of pumping in the area, although the failure to plug the old salt wells contributed to this condition. Unfortunately, attempts to plug the old wells and thus improve the quality of the water in the aquifer would probably be too costly to be justified because location data are not available for most of these wells. Furthermore, even if the wells could be located, there would be no assurance that the mineralization would decrease because the updip migration will continue as long as there is heavy pumping in the area.

Water from the Marshall formation is almost uniform in temperature throughout the year and averages about 52 F. It is reported by some of the users that the temperature of the water has consistently risen through the years following the return to the formation of small quantities of water that had been used for cooling and had become slightly heated. If there has been any rise in temperature, it is probably a local condition.

Michigan formation. —The Marshall formation is overlain by the rocks of the Michigan formation. These rocks are composed primarily of shale and gypsum, with minor beds of sandstone and limestone. A bed of hard, brown to buff, dolomitic limestone usually occurs at the base of the Michigan formation and separates it from the Marshall formation.

The gypsum beds of the Michigan formation are found under the drift and extend from the southern limits of the city of Grand Rapids to a mile or more south of the village of Grandville. Throughout most of this area the gypsum is within 50 feet of the surface. The beds are generally thin but may be as much as 12 feet in thickness and are interbedded with thin beds of shale. In Walker and Wyoming Townships gypsum has been mined for many years.

Gypsum is slowly dissolved by percolating ground water and as a result, some subsidence has resulted in the southwestern part of the area. Because solution has removed segments of the gypsum beds, the drift roof has collapsed in many places. In addition to the depressions caused by subsidence, there are probably secondary fractures, crevices, or large cavities. For example, one of the wells at the Keeler Brass Co. plant in the southwestern part of Grand Rapids was drilled 50 feet deep and finished in a 4-foot crevice in the Michigan formation. The well yields 500 gpm of calcium sulfate water which had dissolved solids of 1,960 ppm and a hardness of 1,390 ppm. (See well 7, table 6.) The analyses of this water are nearly identical to that of water from the company's well penetrating the Marshall formation. This would suggest that the source of water in both wells is the same. However, this well is an exception and in most places the Michigan formation yields small quantities of highly mineralized water.

Bayport limestone. —Plate 3 shows the outcrop of the Bayport limestone. This entire outcrop is covered with a mantle of glacial debris. The formation is composed of white, gray, and bluish limestone and dolomite containing some lenses of sandstone. The Bayport limestone contains small quantities of fresh water. Although no log is available, it is believed that the water from the Mandler Wood Products Co. well (well 8, table 6) is from a sand lens in the Bayport limestone. This formation is not important in the area as a source of water for industrial or municipal water supplies. The glacial drift overlying the Bayport limestone yields enough water to make it unnecessary to drill through the drift.

Other bedrock formations. —Pennsylvanian rocks overlie the Bayport limestone in some areas. The base of the Pennsylvanian system is the Parma sandstone. The Saginaw formation, youngest rock in the area, overlies the Parma sandstone and is composed of beds of shale, sandstone, and some coal.

These Pennsylvanian rocks are covered with glacial drift. The water contained in these formations is usually hard and contains varying quantities of iron, though it is not so highly mineralized as that characteristic of the older bedrock formations. At present, the Parma sandstone and the Saginaw formation are not utilized for water supply by any industry or municipality in this area.

Glacial Drift

In the long period of time that elapsed between the deposition and consolidation of the bedrock in this area and the advance of the glaciers, the bedrock was subjected to uplift, erosion, and many other forces. As the temperature over the continent gradually declined, the winter snowfall exceeded that melted in the summer. The snow accumulated until its great bulk extended to and beyond the Grand Rapids area. Owing to cyclic changes in climate, there were several retreats and readvances of the ice front. Thus, some of the earlier glacial deposits were covered with debris of entirely different character by subsequent advances of the ice. As the climate gradually became more temperate, the ice melted depositing its load of debris, and formed the present surficial deposits.

Glacial deposits may range from stratified to unstratified materials. The stratified materials were deposited from glacial meltwaters and consist of sand, gravel, silt, or clay, which were sorted and laid down in beds. The unstratified materials were deposited directly by the ice and are unsorted mixtures of rock debris that range from clay to boulders.

The glacial deposits of this area—ground moraines, terminal or end moraines, outwash, and lake deposits—are outlined on plate 2. The ground moraine (till plain) and end moraine belong to the unstratified group of deposits and the outwash and lake deposits belong to the stratified group of glacial deposits. The stratified and unstratified material can be clearly differentiated in many places but elsewhere they grade into each other both laterally and vertically. Generally the stratified material yields larger quantities of water than unstratified material. Therefore, if a large quantity of water is needed field investigations and tests should be conducted to find the best location for a well or group of wells.

At any given site the approximate boundaries of the permeable deposits can be determined by properly conducted aquifer tests. Among such tests is one that involves the pumping of a well and the precise observation of the resulting changes in water level in wells nearby. By such tests, sources of recharge and impermeable boundaries can be located and the interference from other wells can be evaluated. From the results of these tests, estimates can be made of how much water can be withdrawn for a given lowering of the water level.

Generally, the mantle of glacial debris in the Grand Rapids area ranges from a few feet to 300 feet in thickness. However, in some places the drift has been entirely removed by erosion.

Moraines and till plains.—Most of the glacial deposits in the Grand Rapids area were formed without stratification or sorting and occur as moraines and till plains. (See pl. 2.) Moraines and till plains are composed of clay, sand, gravel, and boulders. Their texture is compact and heterogeneous and therefore they have a low permeability and yield small quantities of water. However, it should be recognized that surficial deposits represent only the last stages of glaciation and do not necessarily reflect the nature of the underlying materials deposited during earlier stages. Also, small bodies of well-sorted sand and gravel, deposited from local meltwater streams, may be found anywhere in ground and terminal moraines, particularly the latter.

Owing to the lack of information on the structure of the glacial deposits and because of the variable character and thickness of buried deposits, considerable exploration is necessary to locate any underlying sand and gravel that may yield large quantities of water. For example, the city of East Grand Rapids and the Corduroy Rubber Company in northeast Grand Rapids after considerable exploration finished wells in the glacial drift that yield as much as 1,000 gpm. These wells were drilled through the relatively impermeable till at the surface and were finished in coarse deposits of sand and gravel that are buried below the till. On the surface, there is no visible evidence of the permeable deposits below. Perhaps a short distance away the permeable deposit is absent.

Outwash plains.—Outwash plains are underlain by stratified materials that were carried and later deposited by meltwater streams flowing from the glaciers. In general, the materials were sorted into layers of gravel, sand, or clay, depending upon the velocities of the streams carrying the sediment.

The outwash deposits are relatively thin, ranging in thickness from a few feet to 90 feet. Generally, they contain a large amount of permeable sand and gravel and yield large supplies of ground water which is hard but satisfactory for many uses. Well yields as large as 1,000 gpm have been developed in the outwash deposits. The beds of sand, gravel, or silt may grade into each other without much surface evidence, and, therefore, test drilling is necessary to outline the more permeable zones.

The water in the outwash deposits is replenished by precipitation, and accurate records of water level in the formation are needed to indicate seasonal and long-term changes in the position of the water table. With the aid of these data, the amount and distribution of recharge can be evaluated. A knowledge of the amount and distribution of recharge is necessary in order to estimate the maximum quantity of water that may be withdrawn over a long period of time without seriously lowering the water table.

In the Grand Rapids area, the water table slopes toward the streams and, therefore, stored ground water slowly drains into the streams. Some of the water that is now being discharged into the streams can be intercepted by wells. Furthermore, as additional water is pumped from storage, the gradient of the water table may be reversed and water will begin to flow from the streams toward the areas of pumping. This principle of drawing water from a stream through the ground and into a well is called induced infiltration. (See fig. 22.) As more and more water is pumped from storage, steeper hydraulic gradients will be developed on the water table and, as a result, water will flow at increased rates from the areas of recharge to the points of heavy pumping.

Induced infiltration from the streams can be accomplished by pumping wells near the streams in those places where the sand and gravel deposits are hydraulically connected to the stream and are lower than the stream bed. The amount of water that can be obtained by this method will be determined principally by the area of sand and gravel that is in contact with the stream, by the permeability and thickness of the sand and gravel between the stream and the wells, and by the flow of the stream. The closer the wells are to the streams, the steeper will be the gradients which will result in corresponding increases in the induced infiltration.

Where the surface water is softer and less mineralized than the ground water, induced infiltration will improve the chemical quality of the water pumped from the well. This improvement will vary with the distance from the river, the pumpage, and the type of material the water passes through. Furthermore, the filtering action of the material between the stream and the well will remove suspended material, and will serve, to some extent at least, as a filtering and absorbing medium for bacteria, tastes, and odors present in the stream.

The temperature of well water induced from the stream will fluctuate with the seasonal changes of river temperature, although the range of the fluctuations will be much less than that of river water. There will also be a lag in the occurrence of the temperature extremes even a short distance from the stream. These differences will depend on how far the wells are from the stream.

Hydrogeologic conditions are excellent for the use of the induced infiltration principles in many places along the streams in the Grand Rapids area. Hydrologic studies will be necessary to locate the most favorable sites.

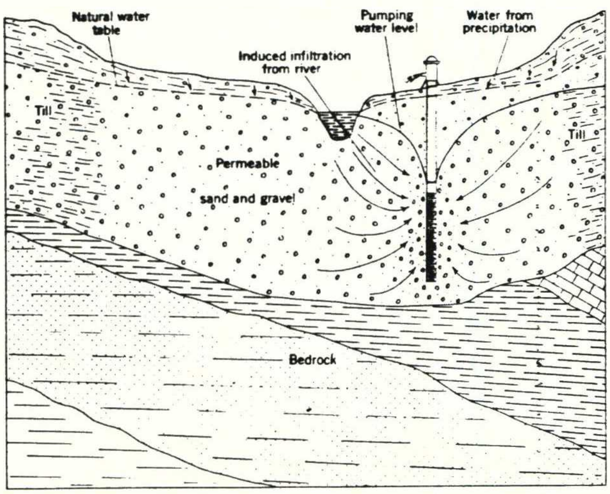


Figure 22. —Generalized diagram showing how water is induced to flow from a river to a pumped well.

Plaster Creek has a very small dry-weather flow (table 4). Therefore, a large ground-water development along Plaster Creek would not be assured of large quantities of water for induced infiltration during dry periods. However, storage in the aquifer along the creek may be large and the effect of short periods of deficient recharge may not be significant in some places. Buck Creek and Rush Creek offer good possibilities for induced infiltration because their dry-weather flows are rather large, and thick sections of outwash materials are present along the course of these streams.

Although Indian and Mill Creeks have substantial dry-weather flows, little is known about the nature of the deposits along the course of these creeks and their use for induced infiltration would require careful exploration to determine whether permeable deposits occur and are hydraulically connected to the streams.

At present (1953), the largest ground-water supplies in the area are developed from the outwash deposits. Wyoming Township is the largest user and has 5 wells in sec. 24 and 3 wells in sec. 13. In general, these wells draw water from storage which is replenished by precipitation. However, in periods of extended droughts the composite cone of depression of these well fields probably reaches to Buck or Plaster Creek and intercepts some water from these streams. (See fig. 22.) These outwash deposits constitute a large ground-water reservoir capable of storing millions of gallons of water.

Lake plains. --In general, the lake-plain deposits are a thin veneer of clay and fine sand that was deposited over sand and gravels. These sands and gravels are probably a buried extension of the outwash deposits as shown on plate 2, and are relatively thin, being generally 25 to 30 feet, and in few places as much as 40 to 50 feet thick.

In general, the sands and gravels deposited in the area mapped as lake plain are very permeable and contain large quantities of water. Considerable explorations by test drilling or by geophysical surveys may be necessary to locate deposits that are favorable for induced infiltration because the deposits along the Grand River are not thick and permeable at all places.

The hydraulic principle of induced infiltration can be applied in the lake-plain area as well as in the outwash plains. However, as most of the area mapped as lake plain lies adjacent to the Grand River, any discussion of induced infiltration will necessarily concern the Grand River. Most of the sand and gravel deposits under the lake plain are probably hydraulically connected to the Grand River and therefore the lake plains are the most valuable area for ground-water development.

The sands and gravels below the lake-plain deposits adjacent to the Thornapple River and some areas adjacent to the Rogue River are capable of yielding large quantities of water to properly designed wells. Sufficient flow is available in both rivers to assure induced infiltration during dry periods.

It is not probable that this type of development could be effective at all places along the Grand, Thornapple, or Rogue Rivers, owing to the variable thickness and permeability of the deposits. However, with properly designed wells or other infiltration systems, the amount of water that can be induced from the rivers may be several millions of gallons per day. Theoretically the quantity of water that could be developed would be limited by the streamflow.

Chemical quality.—The water from the glacial drift is generally of the calcium and magnesium bicarbonate types, with variable amounts of sulfate. Seven analyses of ground water from the drift had a median value of dissolved solids of 447 ppm, and a median hardness of 380 ppm. A rather wide range in chemical quality of water in the area was observed; dissolved solids ranged from 148 to 1,150 ppm and the hardness from 129 to 770 ppm. No definite pattern of the degree of mineralization or hardness was observed. However, in areas where the water from the drift has high mineral content and hardness, the water is principally calcium sulfate in chemical character. This may be attributed to the gypsiferous pebbles and particles in the drift that were picked up by the ice overriding the gypsum beds. Upward flow of the mineralized calcium sulfate water from the underlying Michigan formation may also cause the water in the wells to be more mineralized. Wherever the gypsum deposits in the Michigan formation are connected hydraulically to the main water body in the drift, the water can be expected to be very hard and have a calcium sulfate character. However, the degree of mineralization may be low enough for many uses. The composition of water from the drift wells is shown in figure 23 and the chemical analyses given in table 6. Water in the drift which is in contact with the Michigan formation may be moderate in hardness when first pumped, but continued pumping of the well may induce enough highly mineralized water from the Michigan formation to reduce appreciably the value of the well as a source of usable water. Hamilton, Weeber, and Ward (1947—51) and the Michigan Department of Health (1948) have provided quality of water data which illustrate the condition that must be contended with in any place where ground water is developed from drift in this area. Data in table 7 show that water from drift may be of good quality on first use but can be contaminated by moderately mineralized water from the underlying bedrocks. These analyses are of the water taken from the Wyoming Township wells.

PUBLIC WATER SUPPLIES

Grand Rapids

Almost all of the water supply of the city of Grand Rapids is obtained from Lake Michigan. The Grand Rapids Water Department has a 46-inch pipeline that extends about 28 miles from the city filtration plant to the Lake Michigan pumping station and thence a 54-inch line extends into the lake for 1 1/8 miles. Two intermediate intakes for emergency use are 1/2 and 3/4 miles, respectively, from the shore. A pumping station on the Lake Michigan shore and a booster station at Allendale (about half way between Grand Rapids and Lake Michigan) have sufficient capacity to pump 59 mgd.

The Grand River is the secondary source of water for the city and is used in the summer during peak-demand periods. Before 1940 it was the sole source of supply for the city. Although raw water from the Grand River is inferior in chemical quality to Lake Michigan water, flow of the river throughout the year is adequate to supply the city's demand should the Lake Michigan supply becomes unusable for any reason. Figure 24 shows the annual pumpage by the city of Grand Rapids for the period from 1913—51.

The city of Grand Rapids has storage reservoirs for 53,000,000 gallons, located in various parts of the city. The area served by the city of Grand Rapids is shown on plate 1.

The filtration plant has a designed capacity of 44 mgd. From figure 25 it can be seen that peak demands have reached 63 mgd. Therefore, it is obvious that the present filtration plant is seriously overloaded during peak demands. Furthermore, the city's distribution system is also overloaded. In addition, the present pipeline to Lake Michigan is now operating during peak demands at its maximum design limit. However, the city of Grand Rapids is planning the expansion of its present water-supply facilities.

The daily pumpage by the city of Grand Rapids for the year 1951 and the daily temperature of Lake Michigan water are shown in figure 26.

Table 7.—Total hardness of ground water from Wyoming Township wells, in parts per million

[Pumpage of these wells is given in table 9]

Well number	Date of collection			
	Sept. 14, 1949	Dec. 27, 1949	Mar. 24, 1950	Dec. 20, 1952
1	160	235	282	285
2	268	310	320	395
3	216	360	356	440
4	174	180	220	185
5	156	190	204	305

NON RESPONSIVE

[redacted]

MAP SHOWING LOCATION OF WELLS

1 0 5 Miles

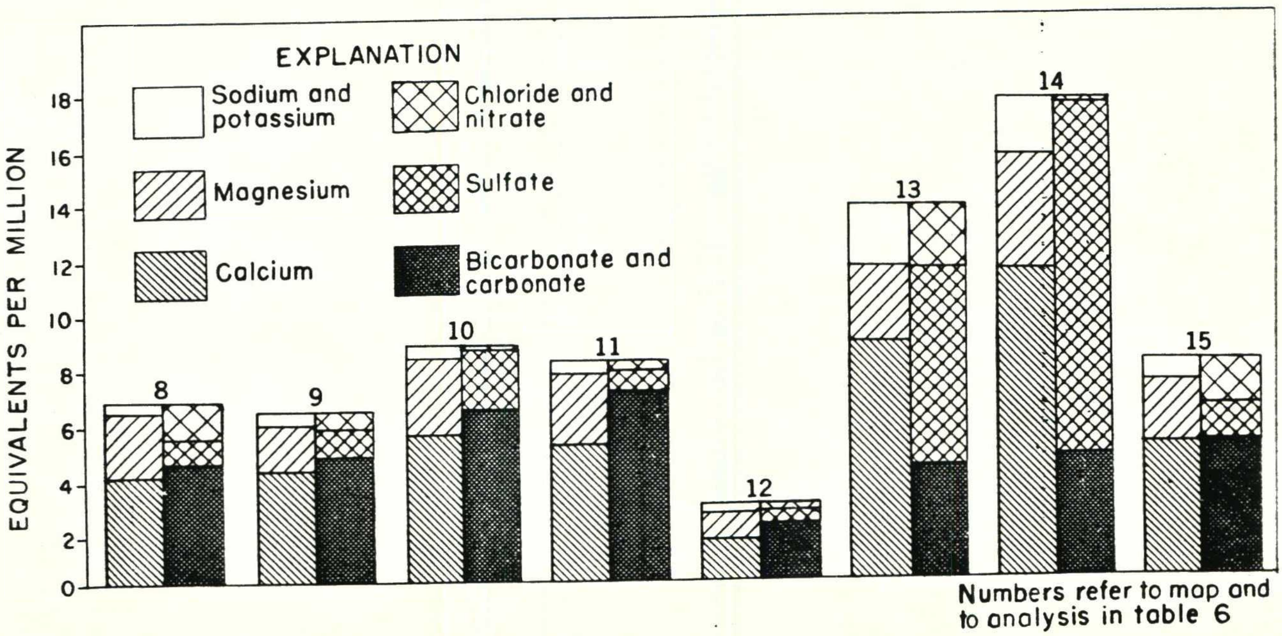


Figure 23. —Composition of water from selected wells in the glacial drift in the Grand Rapids area.

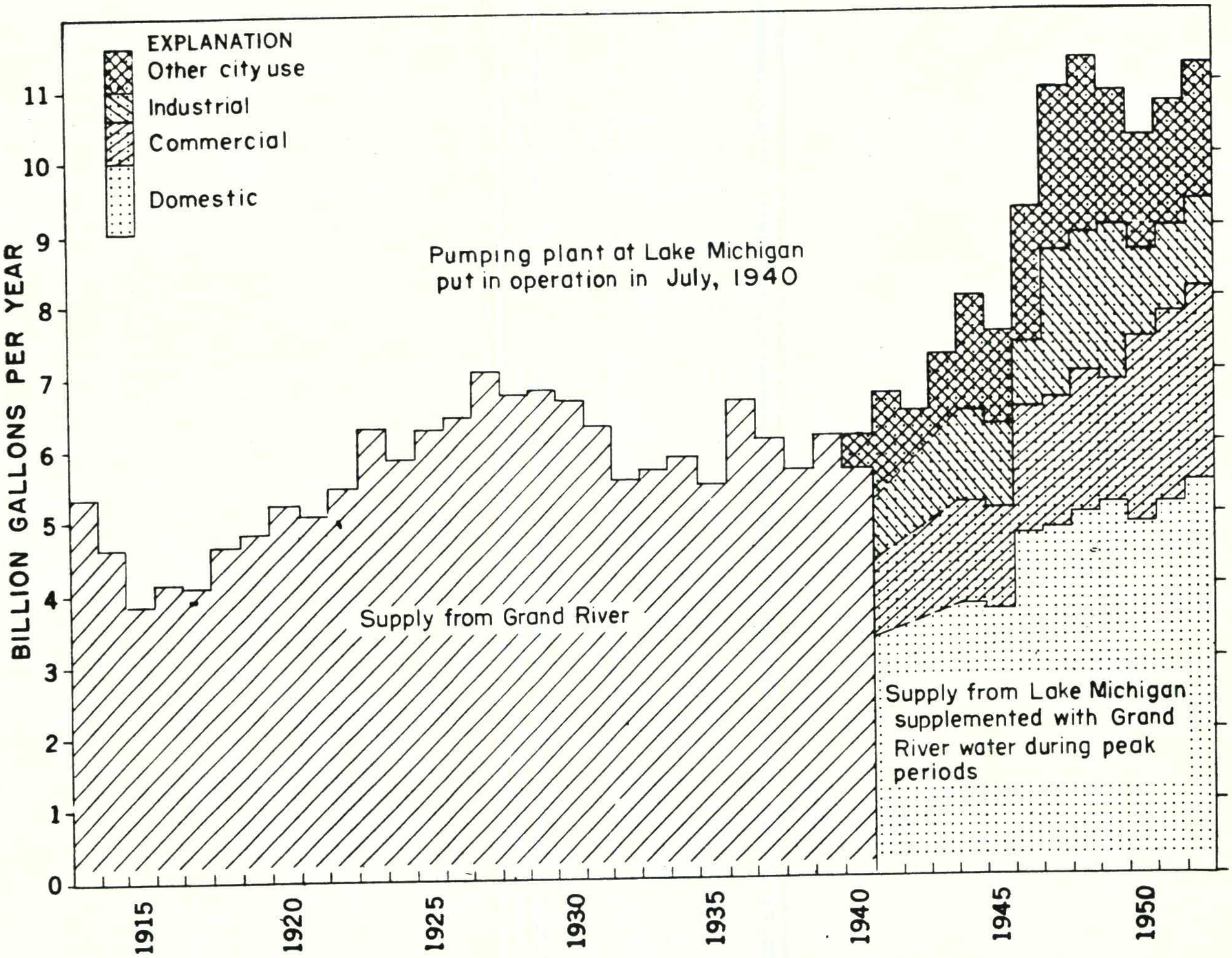


Figure 24. —Annual pumpage by the city of Grand Rapids, 1913—51.

Treatment of Lake Michigan water received at the filtration plant consists of prechlorination, coagulation with alum, sodium fluoride, sedimentation and rapid sand filtration. Grand Rapids was the first city in the United States to fluoridate a municipal water supply as part of a study of the control of tooth decay.

The finished water is of good chemical quality. During 1952 the hardness averaged 137 ppm. The range in concentration of the mineral constituents is small because Lake Michigan furnishes water of relatively constant chemical quality at the intake point. An analysis of water from the Grand Rapids supply is shown in table 8.

The water temperatures range from 34 F to 70 F and average 48 F.

East Grand Rapids

The main source of supply for the city of East Grand Rapids is Reeds Lake which is within the city. In addition to the lake, the city has one well which is about 128 feet deep and obtains water from the glacial sand and gravel. This well is on the west shore of the lake and yields about 800 gpm. However, the well is operated on a standby basis and is used only in peak-demand periods. The well supplies water that has an almost constant temperature of 52 F.

The present water system of East Grand Rapids has a capacity of 4.7 mgd, but will be enlarged to 7.7 mgd. The 16-inch diameter intake is 2,000 feet from the shore and is about 40 feet below the surface of the lake. No treatment of the water is provided except chlorination. However, a small amount of copper sulfate is added directly to the lake about three times a year to control taste and odors produced by aquatic life. Monthly partial analyses of the East Grand Rapids supply are available from July 1944 to December 1950. These show the following extremes:

Determination	Maximum	Minimum
Chloride (ppm)................	20	11
Hardness as $CaCO_3$ (ppm).	229	187
Total alkalinity as $CaCO_3$ (ppm)................	157	129
pH................................	8.1	7.4

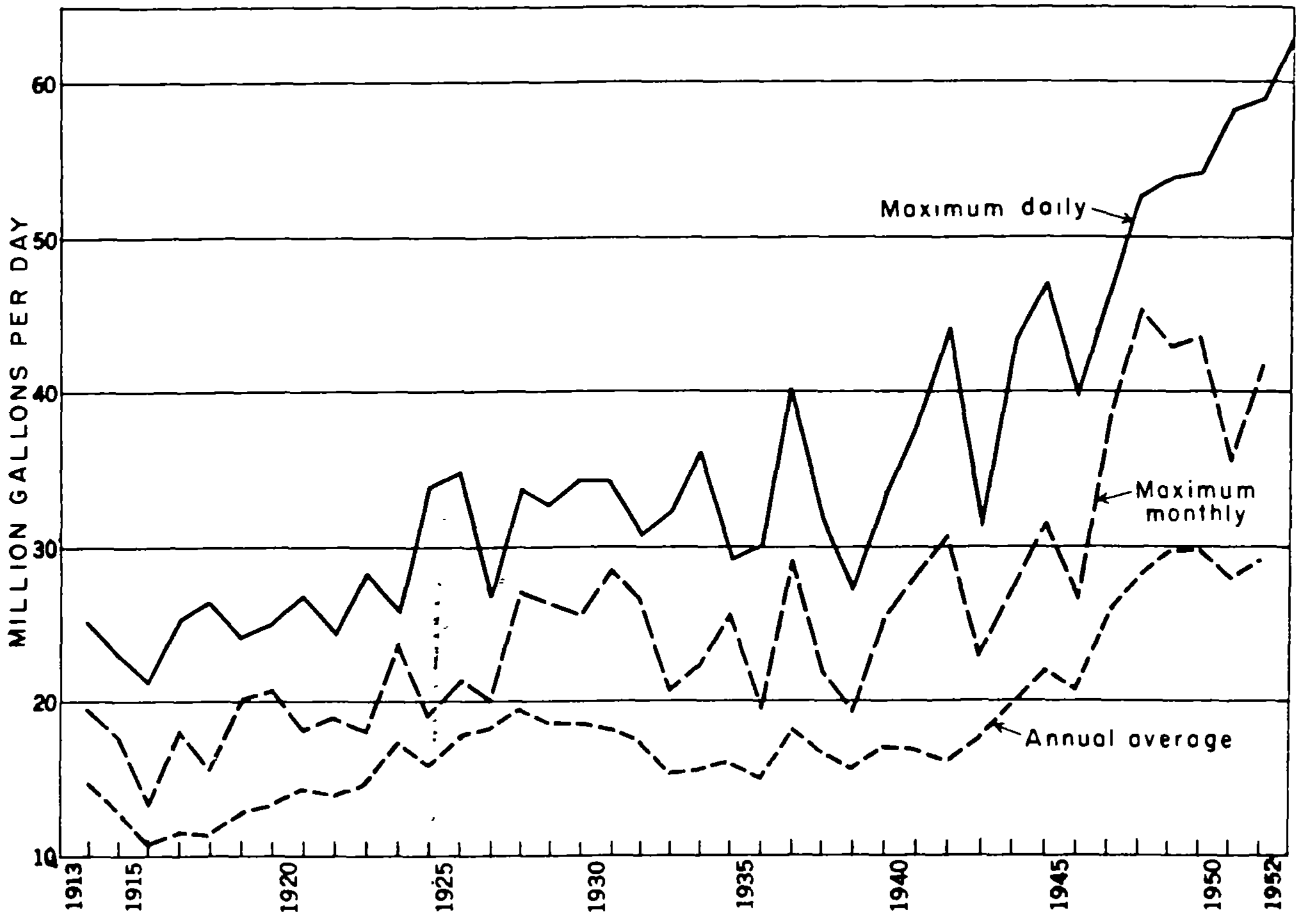


Figure 25. —Maximum daily, maximum monthly, and average annual pumpage by the city of Grand Rapids, 1913—52.

Table 8. —Chemical quality of public water supplies in the Grand Rapids area

[Chemical results in parts per million]

	Grand Rapids	Wyoming Township (Well 5)	East Grand Rapids	Rockford	Grandville
Analyzed by	Grand Rapids Dept. of Water Supply	Michigan Dept. of Health	U. S. Geological Survey	Rockford Municipal Water Dept.	Michigan Dept. of Health
Date of collection	Apr. 22, 1952	Dec. 10, 1952	September 1944	Nov. 9, 1952	Jan. 15, 1945
Calcium (Ca)	35	82	46.5	....	149
Magnesium (Mg)	10	24.3	19.6	....	28.8
Sodium and potassium (Na and K)	10	11	8.7	....	23.9
Bicarbonate (HCO_3)	129	309	172	8	349
Sulfate (SO_4)	33	55	38.8	....	192
Chloride (Cl)	6	14	15	....	40
Fluoride (F)	1.1	0	.15	....	.15
Total solids	209	306	244	....	620
Hardness as $CaCO_3$					
Total	132	305	192	136	490
Noncarbonate	26	50	56	....	194
pH	....	7.5	....	9.2	....

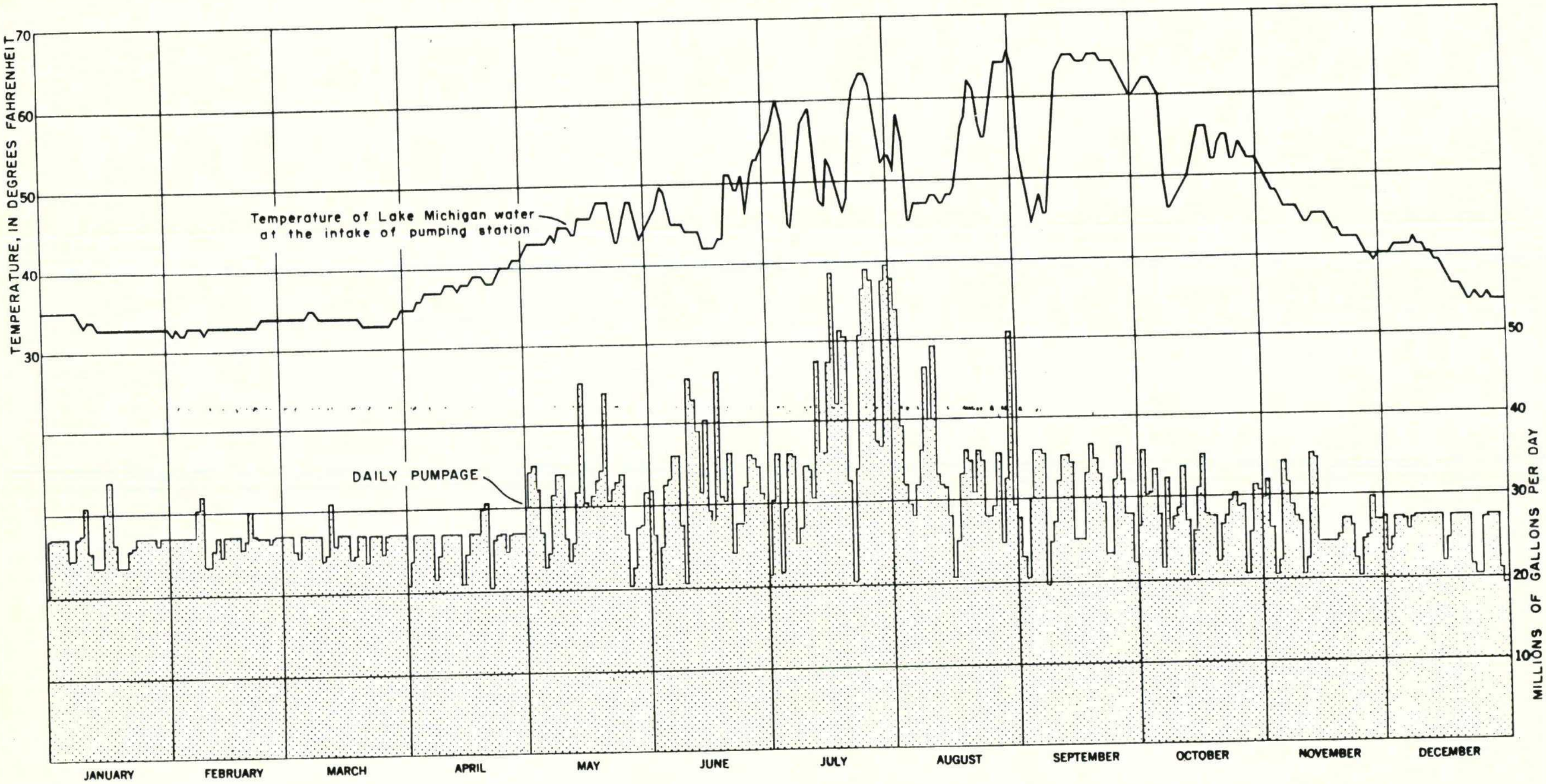
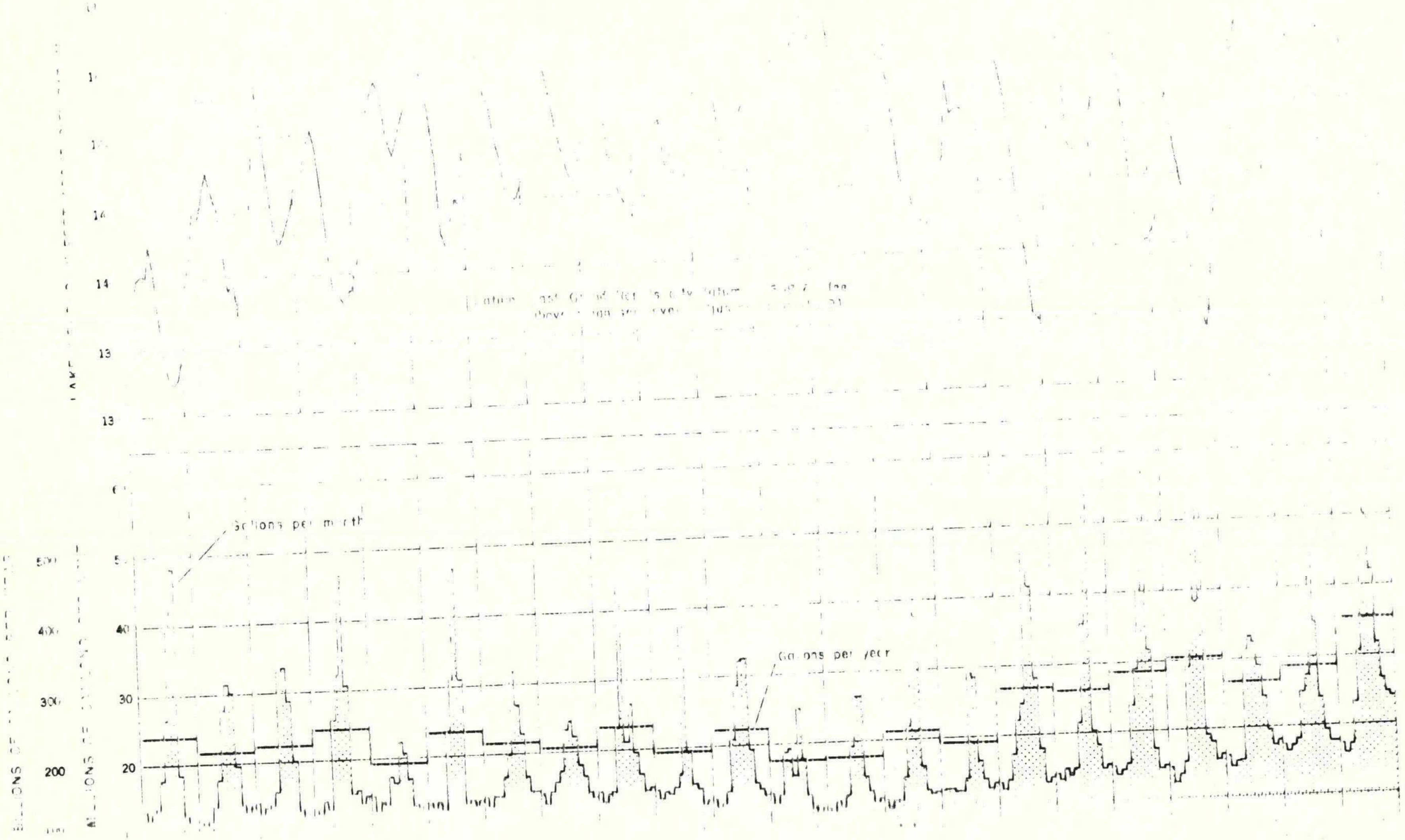


Figure 26. —Daily pumpage by the city of Grand Rapids and daily temperature of Lake Michigan water, 1951.



Gallons per month
Gallons per year
500
400
300
200
40
30
20
14
13
13

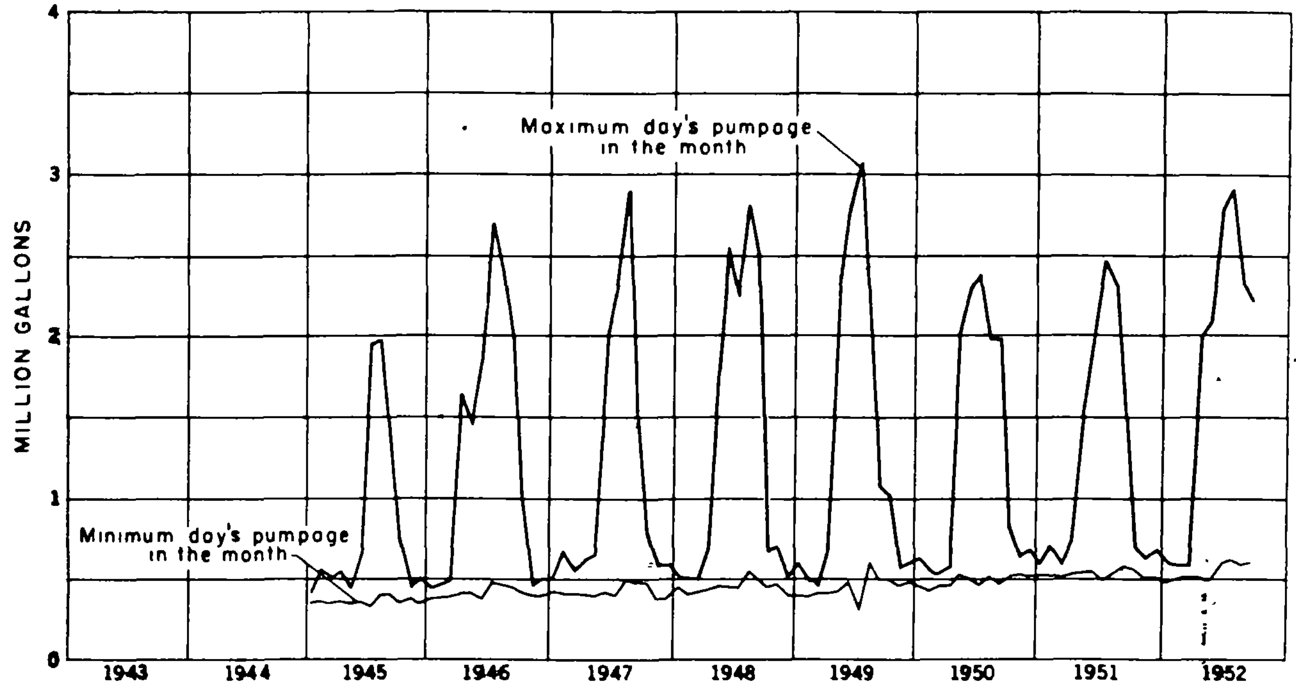


Figure 28. —Maximum and minimum daily pumpage by the city of East Grand Rapids, 1945—52.

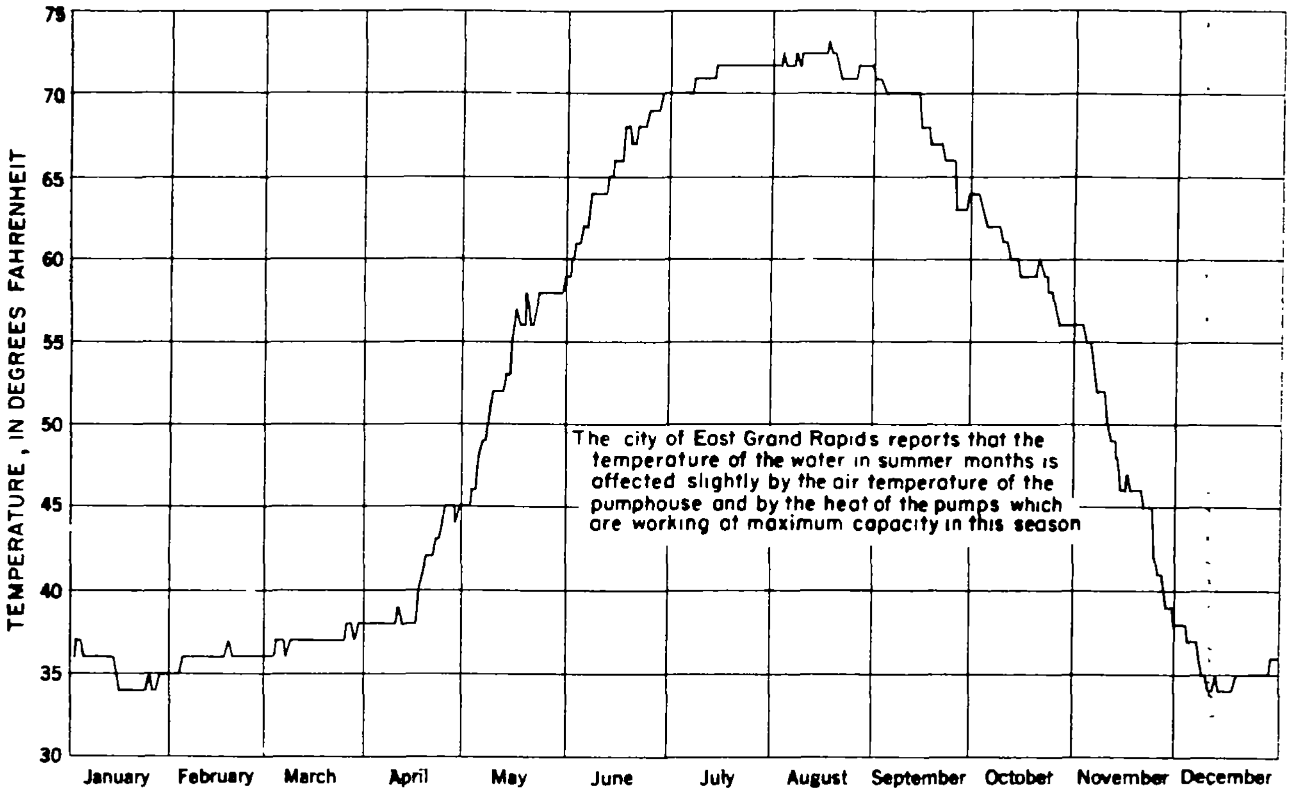


Figure 29. —Temperature of water from Reeds Lake, 1950.

used about 75,000,000 gallons of water in 1952. All water is filtered, softened, and chlorinated. The finished water is moderate in hardness. Chemical quality of the finished water is given in table 8.

PRIVATE INDUSTRIAL AND COMMERICAL SUPPLIES

A part of the surface-water use in the area is for power production although only a very small proportion of the power used in the area is generated at hydroelectric powerplants.

The Consumers Power Co. built a hydroelectric powerplant on the west bank of the Grand River in Grand Rapids in 1917. A canal carries the water from the dam which is about 800 feet downstream from Sixth Street Bridge to the powerplant which is about 500 feet downstream from Pearl Street where the water is discharged back into the river. The average annual use of water during the 10-year period ending in 1950 was about 213 mgd (330 cfs) at an average effective head of about 11.5 feet. A mill situated a short distance downstream from Pearl Street also uses water from the same intake canal.

The Consumers Power Co. operates three hydroelectric plants (Ada, Cascade, and LaBarge) within the area on the Thornapple River and uses most of the head available in the lower 20 miles of the stream. There are also two small dams at and near Rockford on the Rogue River.

One of the most important uses of ground water in the Grand Rapids area is for cooling in many industrial and commerical operations. Ground water in the area is well suited for this use because its temperature is uniform and lower than that of surface water in the summer. In most wells, the water temperature is 50 to 52 F. Ground-water temperature is almost constant, varying only 1° or 2° from the average during the year.

Industrial use of water in Grand Rapids is relatively small, only about 23 percent of the total use. Many industries have dual water-supply systems. They buy water for sanitary use from the city and use ground water for other purposes. There are several large industries that lie outside of the area served by the city and, therefore, must depend on private sources for water supply. In Wyoming Township, there are about five or six large industries that take their supply in part from the township supply and the rest from their own wells. The Nash-Kelvinator Corp. and Reynolds Metals Co. each has one plant, and General Motors has two plants in Wyoming Township. Each of these plants has wells that yield as much as 1,000 gpm.

The quantity of water withdrawn from wells in the Grand Rapids area for industrial uses is not known exactly but it is not large and probably averages about 10 mgd. The water has few uses except for cooling because of its hardness and high mineralization; therefore, withdrawals depend on the weather and temperature. Most industries could not furnish estimates of how much water they use because their wells are on automatic operation and no records are maintained.

Commercial use of water from the Grand Rapids supply is about 24 percent of the water distributed. However, many of the commercial establishments in Grand Rapids have dual water-supply systems. Those using this type of system have wells to supply water for cooling and air-conditioning units. Most of this ground water comes from the Marshall formation. The water is very hard, and for the most part, highly mineralized. (See fig. 21.) Some of the water is discharged directly to the Grand River after use, much of it is pumped into the storm sewer system, and the rest goes into the sanitary sewer system. Only a few concerns return the water to the ground because of difficulties encountered in returning the water and the fear that the heated return water will raise the temperature of the aquifer in the area.

Most of these wells operate only about 10 hours a day during the air-conditioning season. Yields as large as 1,000 gpm have been developed in wells finished in the Marshall formation. Water that is withdrawn from the Marshall formation in the Grand Rapids area is evidently acceptable for cooling and air-conditioning. However, it should be remembered that in some places where water from the Marshall formation is highly mineralized, the water may be very corrosive.

The quantity of ground water used commercially is estimated to be about 1,500 million gallons per year, and averages about 10 mgd during the summer.

IRRIGATION AND RURAL SUPPLIES

A relatively small amount of water is used for irrigation in this area. Most of the water used comes from wells finished in the glacial sands and gravels and is used for commercial truck gardening, both outdoors and in greenhouses. The natural rainfall is generally sufficient for most agriculture and irrigation is not often necessary in the Grand Rapids area, although supplemental irrigation can be valuable during years when the rainfall is less than normal or is poorly distributed.

It is possible to develop enough water from wells for rural use practically anywhere in the area.

POTENTIALITIES

Surface Water

The potential water supply of the Grand Rapids area is practically unlimited when Lake Michigan is considered as a possible source. The available supply from Lake Michigan is far in excess of any possible foreseeable requirements. Any additional demand for Lake Michigan water, however, cannot be met without expansion of existing facilities since the present system to Lake Michigan is already operating at maximum design capacity during periods of peak demand. The water of Lake Michigan is of good chemical quality, although it does require purification for some uses.

The Grand River could furnish enough water to supply the area adequately. Although of less desirable quality than Lake Michigan water, it can be made chemically satisfactory by proper treatment. Records for the period 1930—52 indicate that a supply of about 600 mgd (928 cfs) can reasonably be expected during 95 percent of the time. On the basis of records for the past 22 years, the longest period during which the average flow was less than this amount was 140 days. Even the lowest daily flow on record, 246 mgd (381 cfs), would supply more than four times the maximum capacity of the present Lake Michigan system.

At present, the entire flow of the Rogue and Thornapple Rivers is not utilized except for power development. Based upon the records for the Thornapple River near Hastings, it is estimated that the Thornapple River at its mouth could supply about 37 mgd (57 cfs) during 95 percent of the time without storage. Although streamflow records on the Rogue River are of insufficient length to make a satisfactory estimate of yield, it appears that the low-water flow of the steam is well sustained and definite possibilities for development exist.

Small water supplies could be developed from the small streams in the area.

Ground Water

Moraines and till plains form the land surface in three-fourths of the Grand Rapids area. These features are composed of sediments having relatively low permeability. Therefore, the potential supply of water available from these deposits is low. However, in places permeable deposits that lie buried below the till may yield large supplies of water.

The part of the Grand Rapids area which seems to offer best possibilities for the development of large ground-water supplies is the outwash and lake plains. Here, the large potential is adjacent to and in connection with the surface streams. Sections along the Grand, Thornapple, and Rogue Rivers offer large potentials, in the order of millions of gallons per day. In those areas along the streams where geologic conditions are such that permeable deposits of drift are hydraulically connected to the streams, it may be possible to develop supplies ranging from 10 to as much as 100 mgd. The potentiality of the outwash and lake plains is limited by the streamflow characteristics because the potentiality depends on the flow of the streams to provide water for induced infiltration. The surface-water and ground-water potentials are closely related. One can not be considered without the other because streamflow that is induced into an aquifer and pumped from wells is not available for use from the stream. Generally not all the entire surface- or ground-water potential can be used because it is necessary to leave some flow in the streams at all times. Perennial ground-water supplies as large as 10 mgd or more probably would have to be developed by induced infiltration from adjacent streams.

Small supplies could be developed in other parts of the area adjacent to some of the smaller tributaries to the Grand River. Most of these streams have sufficient base flow to support induced recharge to a well field.

Some of the outwash area could support more development, even though in much of this area induced infiltration might not occur. The relatively high porosity of the sand and gravel makes possible the storage of millions of gallons of water. Development of water from these deposits would depend on recharge from precipitation in the area.

Throughout the whole area, the yield of wells will vary from place to place, because of the wide range in thickness and permeability of the water-bearing formations. Careful exploration and test drilling should precede any development in order to locate the most favorable deposits.

The bedrock aquifers are less favorable as potential sources of water because they contain either small quantities of water or water that is moderate to highly mineralized. Although the water from the Marshall formation is mineralized, the formation yields water in sufficient quantity to make it a good potential source for cooling water and for other uses where the quality of water is not important.

WATER LAWS

Water laws applicable to the area deal mostly with pollution and obstructions to navigation. However, Michigan has a ground-water law restricting unreasonable waste from flowing wells.

The extent and nature of the legal right to use surface waters in Michigan is governed by the riparian doctrine.

The Michigan Water Resources Commission has control over the pollution of any water of the State. Section 8B of the act creating the Michigan Water Resources Commission states: "***it shall be the duty of any person***requiring a new or substantial increase over and above the present use now made of the waters of the State for sewage or waste disposal purposes, to file with the Commission a written statement setting forth the nature of the enterprise or development contemplated, the amount of water required to be used, its source, the proposed point of discharge of said wastes into the waters of the State, the estimated amount so to be discharged, and a fair statement setting forth the expected bacterial, physical, chemical, and other known characteristics of said wastes."

Both the State and the county boards of supervisors have authority to petition the circuit courts for determination of the "normal" level of inland lakes. The State laws require only the approval of the county board of supervisors before any dam or other obstruction is built on streams not controlled by the Department of the Army.

Further information concerning laws governing the surface water of Michigan may be found in the Constitution of 1908, the annual bulletin "Laws Relating to Conservation," and the drain laws of Michigan.

Hydroelectric power projects involving navigation, interstate commerce, or Federal lands are also subject to regulation by the Federal Power Commission.

The Michigan Agricultural Experiment Station (1950) summarized the common law dealing with ground water in the State of Michigan as follows:

"With respect to ground waters the courts now generally hold to the rule of reasonable use. This permits farmers and others considerable freedom in sinking wells on their own lands and in the pumping and ordinary use of ground waters. The rule, however, can be interpreted to prevent wasteful, malicious or other unreasonable water uses, particularly when these have an adverse or injurious effect on others. The courts have indicated that under some circumstances particular water users may be liable to their neighbors for damages if it can be established that their pumping activities have so lowered local water levels as to require the abandonment or deepening of wells previously existent in the vicinity."

The State supervises the locating, drilling, operation, and plugging of wells drilled for gas, oil- and gas-field waste disposal, secondary recovery, and geological information. Such wells penetrating salt or mineral water, when abandoned, are to be plugged in a manner to prevent contamination of fresh water.

SELECTED REFERENCES

Akers, J. F., 1938, Drift thickness map: Michigan Dept. Cons., Geol. Survey Div.

Congressional Documents, 1932, 73d Cong., 1st sess., H. Doc. 80.

Cook, C. W., 1913, Brine and salt deposits of Michigan: Michigan Biol. and Geol. Survey Pub. 15, geol. ser. 12.

Grimsley, G. P., 1904, The gypsum of Michigan and the plaster industry: Michigan Biol. and Geol. Survey, v. 9, pt. 2.

Kelley, W. A., 1936, The Pennsylvanian system of Michigan: Michigan Dept. Cons. Pub. 40, geol. ser. 32.

Leverett, Frank, and others, 1906, Flowing wells and municipal water supplies in the southern portion of the southern peninsula of Michigan: U. S. Geol. Survey Water-Supply Paper 182.

Leverett, Frank, and Taylor, F. G., 1915, The Pleistocene of Indiana and Michigan and the history of the Great Lakes: U. S. Geol. Survey Mon. 53.

Michigan Agriculture Experiment Station, 1950, Land Economics, v. 26, no. 3, August 1950, East Lansing.

Michigan Dept. Health, 1948, Chemical analyses and their interpretations of public water supplies in Michigan: Eng. Bull. no. 4.

Mitchell, W. D., 1950, The water supply characteristics of Illinois streams: Illinois Div. of Waterways.

Monnet, V. B., 1948, Mississippian Marshall formation of Michigan: Am. Assoc. Petroleum Geologists Bull., v. 32, no. 4, p. 629-688.

Newcombe, R. B., 1933, The oil and gas fields of Michigan: Michigan Dept. Cons., Geol. Survey Div., pub. 38, geol. ser. 32.

Ries, Henrich, 1903, Clays and shales of Michigan: Michigan Biol. and Geol. Survey, v. 3.

Riggs, C.H., 1938, Geology of Allegan County, Mich.: Michigan Dept. Cons., Geol. Survey Div., progress rept. 4.

Rominger, C. L., 1876, Geology of the Lower Peninsula: Michigan Geol. Survey, v. 3, pt. 1, p. 1-216.

U. S. Geol. Survey, issued annually, Surface-water supply of the United States, part 4, St. Lawrence River basin: Water-Supply Papers.

U. S. Bureau of Census, 1951, United States Census of Population, 1950.

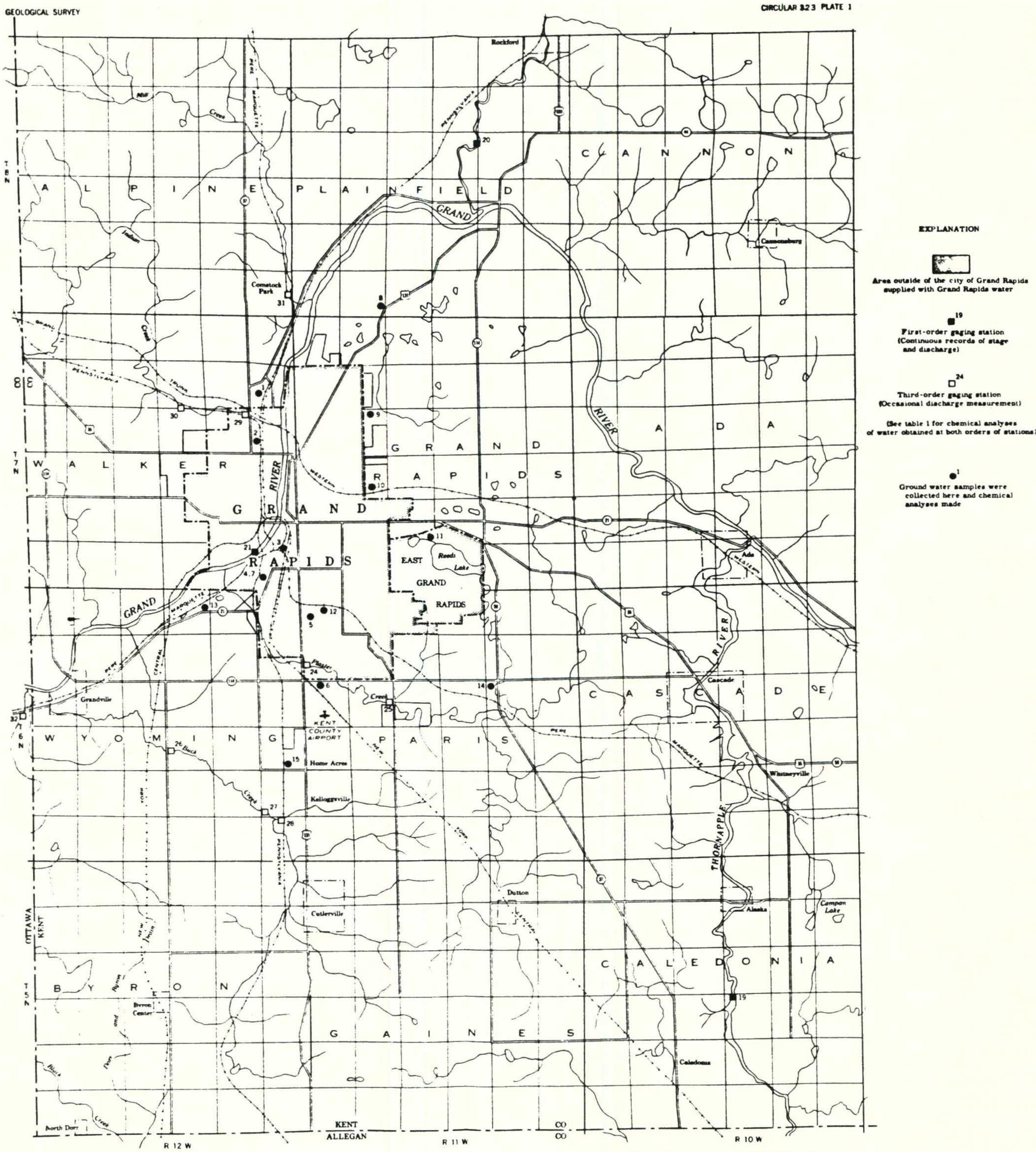
U. S. Weather Bureau records, 1950, Local climatological summary, Grand Rapids, Mich.

Winchell, Alexander, 1861, First biennial report of the Geological Survey of Michigan—Lower Peninsula, Lansing, 399 p.

Unpublished References

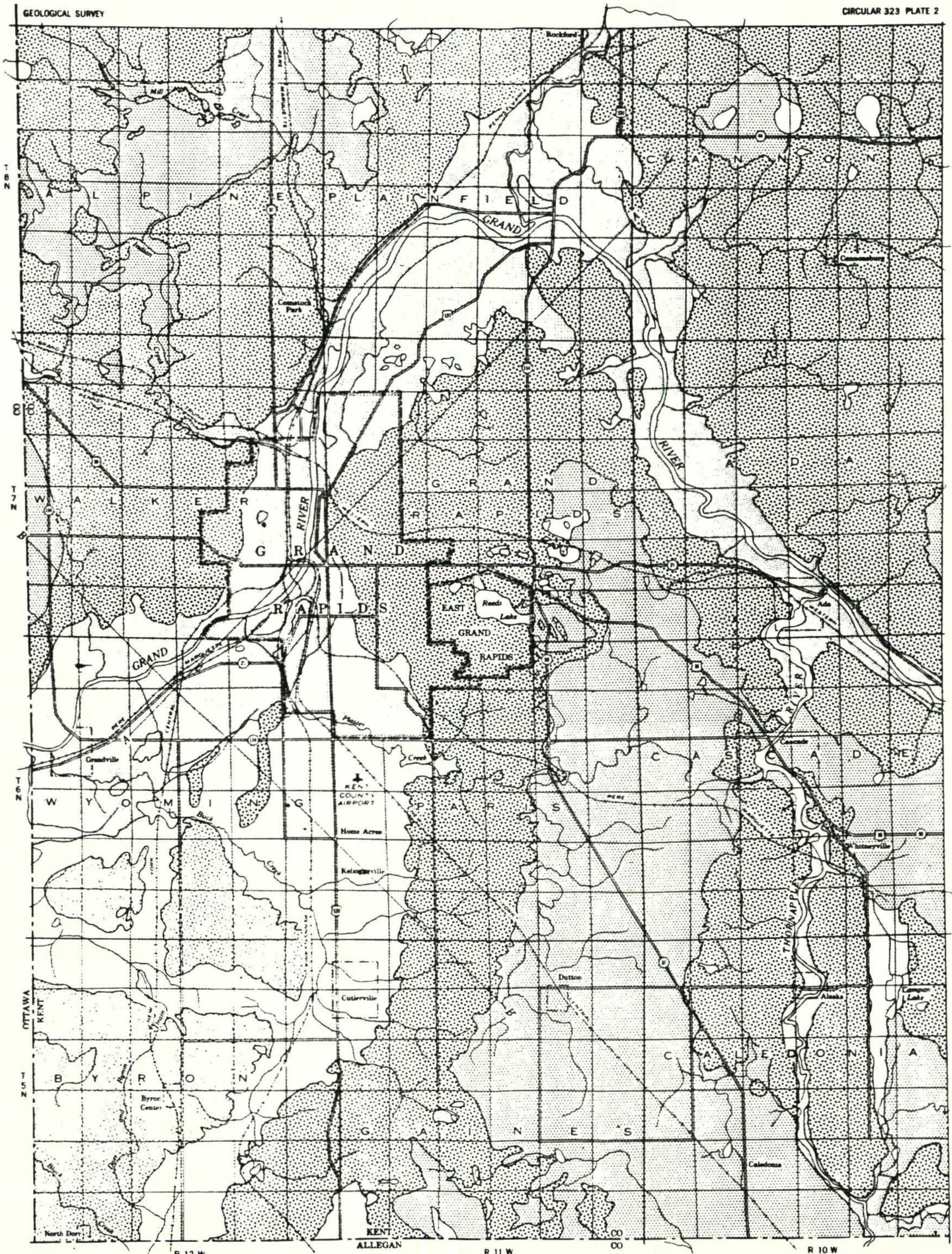
Hamilton, Weeber, and Ward, 1947—51. Consulting Engineers, Grand Rapids, Mich. Report on extensions to water distribution system for Wyoming Township, Kent County, Mich.: 5 reports.

Martin, Helen, 1953, Glacial geology map of Kent County: (manuscript map in files of Michigan Geol. Survey, Lansing, Mich.).



MAP OF THE GRAND RAPIDS AREA SHOWING LOCALITIES WHERE WATER RESOURCES DATA HAVE BEEN COLLECTED

1 0 5 Miles



The distribution of the glacial deposits as mapped applies only to conditions at the surface
The deposits and their water-bearing properties may be expected to change with depth.
Test drilling is generally necessary to locate large water supplies

Geology from unpublished maps, by Helen M. Martin, Michigan Geological Survey, 1953

EXPLANATION

Pleistocene

Water-covered areas
Marshes, swamps, lakes, and streams

Till plain
Supplies for domestic use:
Some large supplies of water may be developed from inter-bedded sands and gravels or buried outwash deposits

Moraine
Supplies for domestic use:
Some large supplies of water may be developed from inter-bedded sands and gravels or buried outwash deposits

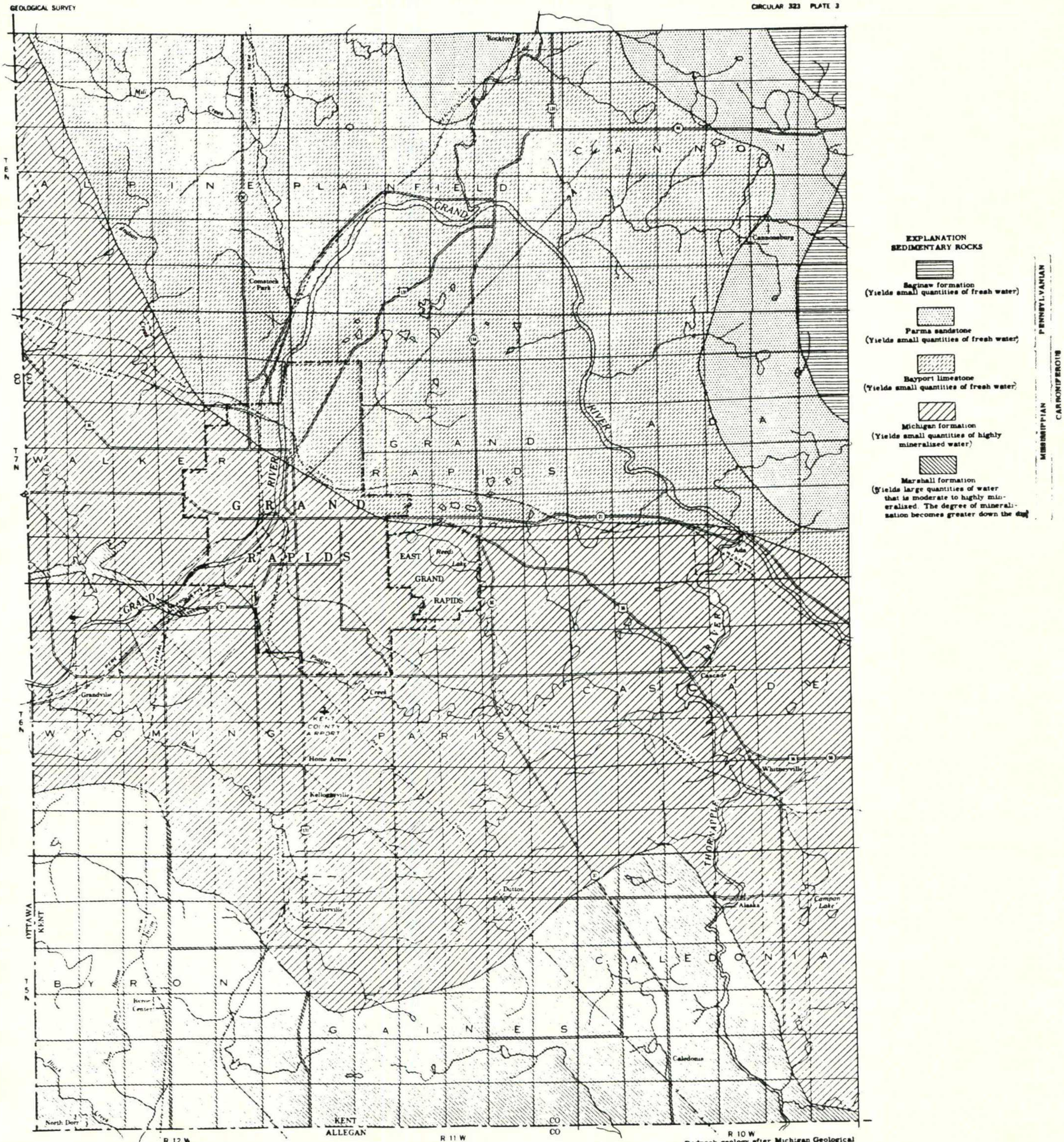
Outwash deposits
Large supplies of hard but fresh water may be developed in these deposits

Lake plain
Large supplies of water may be developed from sand and gravel below these generally fine-grained deposits. Locally the water may be mineralized. Induced infiltration from these deposits possible in many places along Grand River

Section A-A' and B-B' are shown in fig. 19

MAP OF THE GRAND RAPIDS AREA SHOWING GLACIAL DEPOSITS AND THEIR WATER-BEARING PROPERTIES

1 0 6 Miles



GEOLOGIC MAP OF THE GRAND RAPIDS AREA SHOWING BEDROCK FORMATIONS